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JAN 78 E D MCCONKEY, A G HALVERSON DOT-FA72WA-3098

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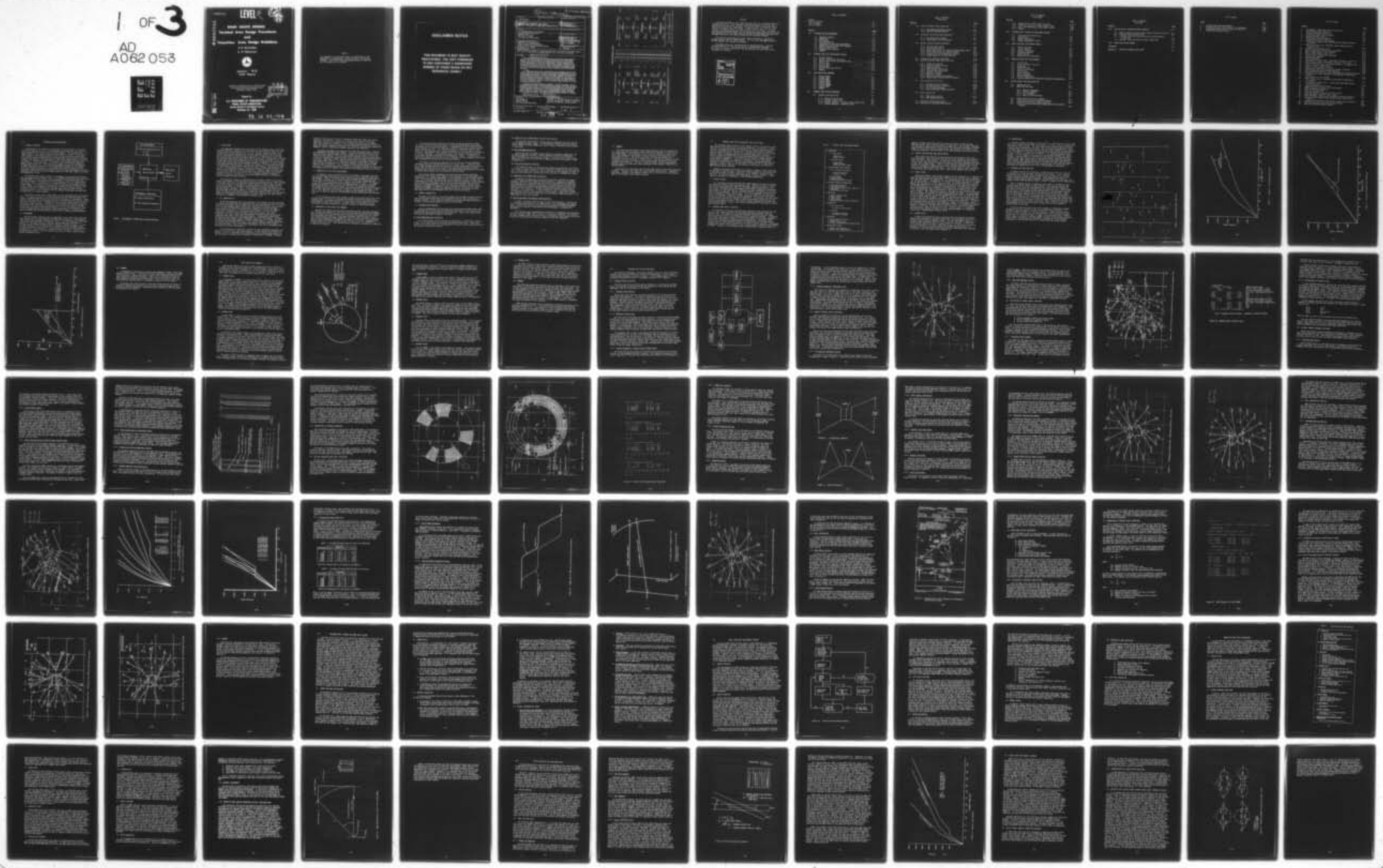

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RNAV ROUTE DESIGN

Terminal Area Design Procedures and Transition Area Design Guidelines

E. D. McConkey

A. G. Halverson

DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

January 1978

Final Report

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16. Abstract

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This report presents techniques which can be used to produce terminal and transition area route structures that are designed for use by aircraft equipped with area navigation (RNAV) computers. The route design processes were developed during several years of investigation into RNAV route structures for terminal and enroute airspace. The design techniques provide for the consideration of user and Air Traffic Control (ATC) requirements. Among the user considerations are minimization of the number of waypoints and the reduction of aircraft time and fuel penalties by utilizing the RNAV routes. The ATC considerations include procedural separation of arriving and departing aircraft, organization of the terminal area according to traffic flow, and provision for sufficient maneuvering airspace to permit efficient traffic separation procedures.

The terminal area design process is characterized by a set of procedures by which the route structure is developed. The data requirements and the data processing programs which can aid in the design process are described. The terminal design procedure describes the means by which the terminal waypoints can be located by considering traffic demand. Techniques for locating feeder fixes and providing traffic patterns for several active runway combinations are included. Procedures for developing efficient vertical aircraft profiles are described. Finally, methods are described for evaluating user benefits for different route structures. The design procedure is iterative in nature and can be repeated as necessary to achieve satisfactory routes for both the user and ATC. Additionally, periodic coordination with adjacent airspace designers is very important throughout the design procedure.

The transition area design guidelines are presented as a series of case studies. The general considerations of developing transition area RNAV route structures are discussed prior to the development of the case studies. These considerations cover the general areas of data requirements, terminal-transition area interface, one way routes, RNAV SID and STAR routes, low altitude route structure interface and crossing airways. The traffic characteristics of several areas of the country are described. To illustrate the transition design concepts, four specific examples of transition routes are presented. The examples include Miami-northeast, Chicago, the California Corridor and New York. Finally, a summary of the transition route design guidelines is presented.

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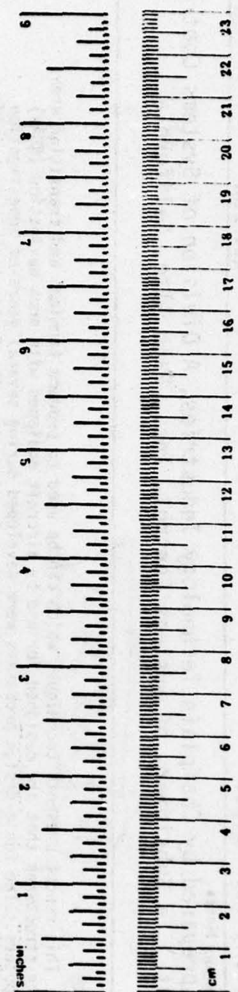
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

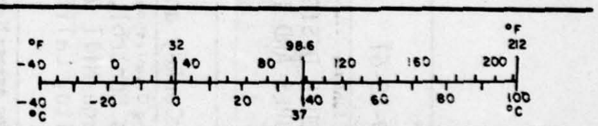
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The work described in this report was the result of a combined effort by Systems Control, Inc. (Vt), Champlain Technology Industries Division, West Palm Beach, Florida and the National Aviation Facilities Experimental Center (NAFEC) of Atlantic City, New Jersey. Systems Control, Inc. (Vt) is a subsidiary of Systems Control, Inc.(SCI) of Palo Alto, California. The RNAV terminal area design procedures and the design evaluation software descriptions were produced by SCI(Vt) under Contract Number DOT-FA-WA-3098, Task Order 014. The RNAV transition route design guidelines were produced by NAFEC.

The SCI(Vt) program manager was Mr. Donald Richardson. The SCI(Vt) project engineer was Mr. Edwin McConkey. Mr. Eric Bolz developed a portion of the terminal area evaluation software.

The NAFEC effort was directed by Mr. A. George Halverson. The FAA Technical Monitor for this project was Mr. Ricardo Cassell of NAFEC. Mr. Cassell's overall coordination and guidance were of significant value throughout the program.

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1.0 INTRODUCTION AND BACKGROUND

1.1 PURPOSE OF REPORT

The purpose of this report is to provide airspace designers with guidelines and procedures to aid in the development of terminal and transition area route structures that utilize area navigation (RNAV). The airspace under consideration in this report consists of that used by aircraft as they depart from a runway to the time they reach cruise altitude and that airspace used by aircraft as they descend from cruise altitude until they land on the active runway at the airport. The development of the route design process is outlined in Figure 1. The design process is the result of considerations from three general areas, that of the user, air traffic control and the environment in which each must function. The following paragraphs discuss the relationship of RNAV route design to each of these operational constraints. As a result of this systematic consideration of the many factors which affect aircraft operations, the guidelines and procedures which have been developed are suitably broad and flexible such that the concepts apply to a very wide range of aircraft and geographical areas.

The terminal area design process is presented as a progression of step-by-step procedures which ultimately result in an RNAV terminal area route structure. The development of these routes can be approached in this manner due to the relatively fixed or structured nature of the terminal area. All routes within the terminal begin or terminate at an airport which has a fixed location with fixed runways. The runways, in turn, have fairly fixed traffic patterns and the traffic demand is also generally stable over a period of weeks or months. All of these "specifics" concerning the terminal area, tend to create a certain orderliness which in turn indicates that the terminal area route structure may be developed in a stepwise manner.

The transition area, on the other hand, is less structured than the terminal area. The route anchor points tying the terminal to the transition area are a series of boundary waypoints whose locations are arbitrary to some degree. These waypoint locations must be developed subject to considerations of both the transition and the terminal area. In addition, the transition routes must be tied to the enroute route structure. Therefore a certain degree of flexibility must be available to the transition route designer to provide a satisfactory linking of the routes to each of these adjoining areas. In order to maintain this flexibility of route design, the transition area design process is presented as a series of RNAV route design guidelines rather than a stepwise design procedure.

1.2 BACKGROUND

The route design processes that are presented in this report have resulted from several years of investigation into RNAV route structures. The results of these studies are reported in References 1 and 2. The work reported in Reference 1 was almost entirely devoted to terminal area airspace while the work in Reference 2 considered the route structure design in enroute airspace. In both of these studies it was recognized that a systematic design procedure, which included the terminal area, transition area and enroute area airspace designers, was required for the development of compatible route structures. Without a coordinated effort there is the ever present possibility of major route structure design incompatibilities.

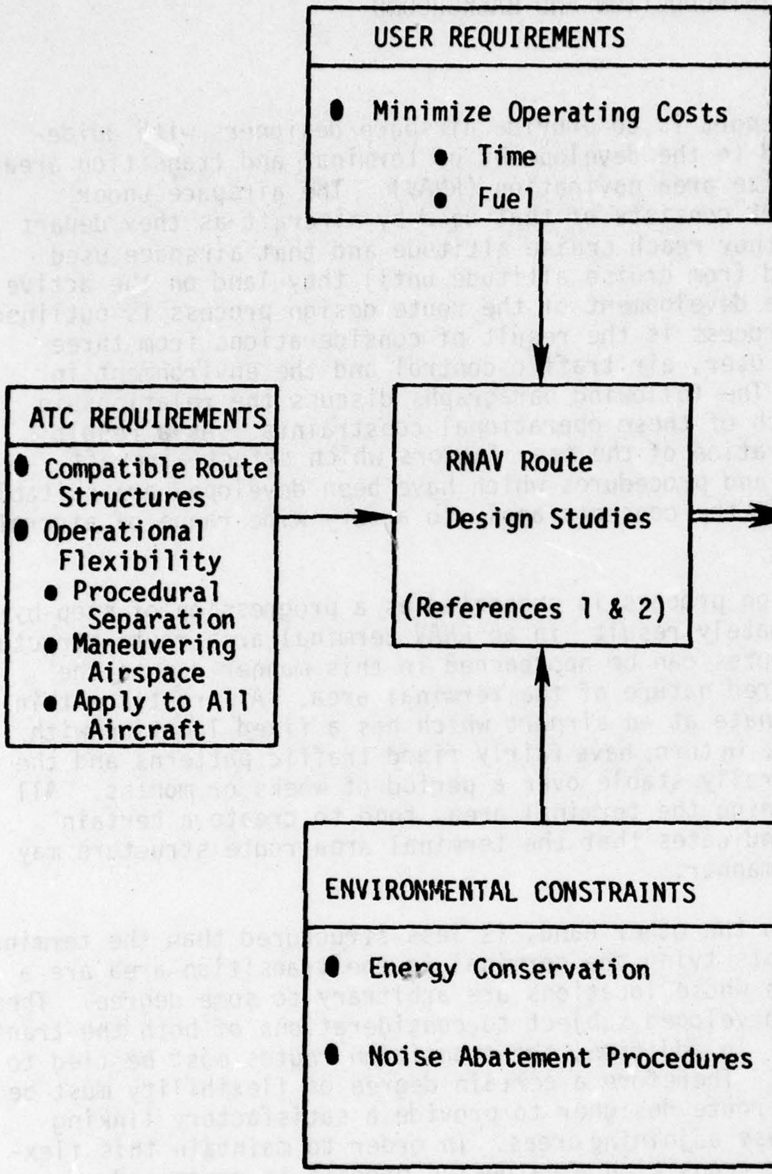


Figure 1 Development of RNAV Route Design Guidelines

1.3 DEFINITIONS

For conceptual purposes only, the extent of the terminal area at most high and medium density airports was considered to be 45 nm from the center of the major airport in the terminal area. At this distance from the airport, most aircraft are outside the domain of the local approach control facilities and are on, or approaching, their enroute flight path. In addition, at 45 nm from the airport many aircraft are transitioning to the high altitude route structure and are above the nominal beginning of the flight levels at 18,000 ft msl. Most of the users of the low altitude airspace are well established on their enroute flight paths before the 45 nm conceptual boundary is reached. In certain metroplex areas where multiple major airports are located, it is desirable to expand the definition of the extent of the terminal area slightly. The procedure that is used in the metroplex areas to define the extent of the terminal area is to draw a circle around the terminal area which is slightly larger (5-10 nm) than a circle which contains all of the feeder fixes that are used by the terminal approach control at the present time. This procedure generally produces a conceptual terminal area that has a 45-60 nm radius and that is centered at a point in between the major airports.

The transition airspace is defined as that airspace in which the aircraft leaves the boundary of the conceptual terminal area and arrives at cruise altitude or descends from cruise altitude and crosses into the terminal area. The transition area airspace is considered to apply primarily to high altitude traffic. Low altitude traffic is assumed to have reached the enroute altitude prior to leaving terminal airspace. Again, in the transition airspace the design concepts have been made sufficiently broad to include both high performance aircraft which can achieve cruise shortly after leaving the terminal area, and very heavily loaded transcontinental and transoceanic aircraft which may not reach cruise altitude for a number of miles beyond the terminal area.

1.4 ATC COMPATIBILITY

The design procedures that are presented in this report have been conceived in a manner such that they are compatible with the requirements of the air traffic controller who handles traffic within the transition and terminal area airspace. In all of the airspace under consideration, maneuvering airspace has been reserved which will permit the controller to separate aircraft using RNAV or radar vector procedures in a safe and efficient manner. No new or exotic navigation or traffic control procedures have been assumed. The route structures that result from using these design procedures generally should be compatible with radar vector control procedures. Consequently, these route structures can be used in a mixed RNAV/radar vector ATC environment. For those aircraft that are on RNAV routes, procedural separation of all routes has been considered in the design guidelines. This provides 1000 ft. vertical separation on crossing routes within the terminal area and at altitudes below FL290 in the transition area. Also route width requirements that are in accordance with FAA Advisory Circular 90-45A apply.

The minimization of controller workload has been considered throughout the terminal and transition route design process. In the terminal area design procedures, traffic is separated into alternating arrival and departure sectors so that the general terminal traffic pattern is constructed in a manner to reduce

potential conflicts and to utilize procedural separation rather than active controller intervention. Likewise in the transition area, arrivals and departures are kept on separate routes, which may be charted or uncharted, until they attain cruise altitude. This design guideline produces arrival and departure traffic separation throughout the transition area and thus reduces the number of conflict resolution problems required of the controller.

The design procedures and guidelines have been made sufficiently flexible to accommodate increased traffic demand. In both the terminal and transition areas provisions have been made for the alignment of the traffic flow by considering traffic demand. This procedure may be repeated as often as necessary to evaluate terminal and transition area route structures under differing traffic situations. Additional traffic demand considerations have been given to the route separation criteria. In areas where airspace is available, routes are separated by a distance that is sufficient enough to permit the use of RNAV parallel offset procedures. This procedure is particularly helpful to the controller in providing separation assurance in overtake situations for transition area departures and in terminal and transition area spacing of arrival aircraft.

1.5 COMPATIBILITY WITH USER REQUIREMENTS

In addition to being compatible with ATC procedures, the route structures that are developed from these design processes are quite compatible with user requirements. Some of the design tools and the design evaluation techniques for the terminal area make use of minimizing the aircraft fuel consumption and flight time as the aircraft arrives or departs the terminal area. For example, routes that are developed which have extended periods of flight at altitudes below the optimum for that aircraft are identified in the design procedure and flagged so that the route designer can go back and modify the route structure to make the route more satisfactory in terms of time and fuel penalties to the user. This iterative type of design procedure can be repeated as often as necessary in order to minimize user penalties for operations within the terminal area.

In the transition area, every attempt is made to give each transition route the most direct path possible between the terminal area and the enroute area. Considerations of airspace availability and crossing traffic may make this goal unattainable in specific instances. In these cases, user benefits and ATC constraints are both considered to achieve a solution to the design problem.

1.6 COMPATIBILITY WITH OTHER FAA PROGRAMS

Because the terminal and transition area design process has been developed by minimizing user penalties, the route structures that are produced by following these procedures are very compatible with existing FAA programs for noise abatement and energy conservation. The descent procedures that are found in this route design process are highly compatible with the "profile descent" procedures that are being implemented throughout the country at this time. Throughout the design process the vertical descent profile of the aircraft is compared to a standard descent profile. This descent design procedure is operationally identical to the profile descent.

The terminal design procedures and transition design guidelines extend the use of a vertical aircraft profile for the purpose of energy conservation into departure and climbout procedures. A departure profile is used to achieve energy savings in climb. This departure profile is based upon the most desirable climb characteristics of several representative aircraft found in civil aviation. The combined climb and descent profiles in this report are referred to as vertical envelopes. The envelopes used in this report are representative of aircraft that were considered in the Reference 1 study. If experience or operational reasons call for the use of a different vertical envelope, the profile can be changed as necessary by the airspace designer.

The terminal area design procedures call for the use of noise abatement procedures that have been developed for the terminal area. In addition, the use of RNAV equipment permits the designer to locate routes over less sensitive noise areas and the use of the vertical envelope design procedure provides assurance that aircraft will be kept at the highest possible operational altitude to achieve both reduced noise and improved fuel efficiency.

The terminal design procedures and transition route design guidelines contained in this report should remain valid regardless of the development and implementation of planned improvements in ATC procedures or new aircraft developments. The procedures and guidelines are sufficiently flexible to permit the accommodation of new aircraft and new traffic handling procedures as they develop. Some of the design standards, such as the vertical envelopes, may have to be modified to accommodate new aircraft but the design procedures should remain generally unchanged. In addition, some of the design tools which are used to evaluate the route structures may need modification to include new aircraft when these vehicles are introduced into civil aviation operations.

1.7 AVIONIC CAPABILITIES

Throughout this report it has been assumed that the RNAV equipped aircraft that will be using these routes have capabilities which meet or exceed some minimum standard. In this way the controller knows that the RNAV aircraft can respond in a predictable manner to specific ATC requests.

1.8 IMPLEMENTATION PROBLEMS

Several implementation problems must be solved before the RNAV routes that are developed by the procedures and guidelines contained in this report can be incorporated into regular terminal area operations. Some of the problem areas that must be addressed include the following:

- <u>Mixed RNAV-VOR Route Structures</u>

Until RNAV becomes the primary mode of navigation in the National Airspace System it will be necessary to support and maintain VOR routes. These VOR routes and the RNAV routes must be compatible in order to avoid traffic conflicts and excessive controller workload.

- **Compatibility of RNAV Routes and ATC Sectorization**

Existing ATC sectorization is based upon the VOR route structure and the traffic demand on these routes. The development of RNAV routes and shifting traffic demand from VOR to RNAV will cause a need to resectorize the airspace in some areas.

- **Mixed VOR-RNAV Operations**

During the time that RNAV traffic demand is increasing, controllers can use RNAV procedures to control suitably equipped aircraft and VOR-radar vector procedures for the remaining aircraft. Training will be required to familiarize controllers with the use of RNAV during the interim phase of RNAV implementation.

- **Pilot and Controller Training**

A considerable amount of education and training of controllers and pilots is necessary in order to achieve the full benefits of RNAV for the users and for ATC. Some recurrent training for controllers may also be necessary in order to maintain their RNAV skills during the initial periods of low RNAV utilization.

- **Compatibility of RNAV Route Structures**

Throughout the RNAV route design process periodic coordination between terminal, transition and enroute airspace planners is necessary to provide assurance that the route structures and traffic flow patterns are compatible. This coordination is especially necessary in high density areas such as the Golden Triangle (Chicago-Boston-Washington) and the California Corridor Area (Los Angles-San Francisco). Periodic coordination between closely spaced terminals is also necessary. In the northeastern part of the United States, the conceptual terminal area boundaries nearly overlap. Compatible terminal and transition area traffic flows must be established in these locations if full RNAV benefits are to be achieved.

- **Minimum Equipment Performance Characteristics**

In order to develop effective and efficient ATC procedures, a minimum set of performance characteristics for RNAV avionics must be developed and agreed upon. A discussion of many of the problems associated with RNAV performance characteristics and their relationship to ATC procedures is contained in Reference 3.

These and many other implementation problems will undoubtedly be encountered before an effective RNAV route structure is available in the NAS. The solution to these problems can be achieved through a coordinated effort between the various services of the FAA and the numerous elements of the user community.

1.9 SUMMARY

The transition and terminal area design guidelines that are contained in this report have been developed through careful consideration of both ATC and user requirements. The procedures are sufficiently flexible to permit their use in low, medium and high density areas using both conventional and high performance aircraft. The design procedures for both the terminal and transition area are iterative in nature; that is, they may be repeated as often as necessary in order to achieve a satisfactory route structure for both the controller and the pilot. The use of these procedures assures a coordinated, workable route structure which takes advantage of the inherent flexibility of area navigation.

Sections 2-4 of this report describe the RNAV terminal area design procedures in detail. Sections 5-10 contain the transition design guidelines. Appendix A describes, in detail, the computer software that is used to aid in the development of the terminal route structure design.

2.0 TERMINAL AREA DATA REQUIREMENTS AND DESIGN TOOLS

The following three sections of this report contain a description of the RNAV terminal area design aids and design procedures. The purpose of these sections is to provide planners and designers of terminal area airspace with a set of procedures which they may use to develop safe and efficient RNAV terminal route structures. Specifically, Section 2 describes the data items that are useful in developing effective terminal RNAV route structures. Section 3 describes several data processing programs that can be used to aid in the terminal procedure. A very detailed description of these programs can be found in Appendix A. Section 4 contains a series of steps which constitute the terminal area RNAV design procedure. The design procedure is iterative in nature; that is, several steps or combinations of steps may be repeated as often as necessary in the process of achieving a satisfactory RNAV terminal route structure.

Before the terminal design process can begin, a number of data items must be available to the designer. These data items are generally information that is available to the air traffic personnel at the TRACON or approach control facility. An outline of these data requirements is shown in Table 1. These items are discussed in some detail in the following paragraphs.

2.1 AIRPORT LAYOUTS

It is necessary to have available the runway patterns at both the primary and satellite airports within the terminal area. Satellite airports of particular interest are those with published instrument approach procedures. Any significant information about the runways such as their length and orientation with respect to true north and the latitude-longitude coordinates of the thresholds should be obtained. Special restrictions such as weight limitations and hours of operation should also be noted. It is also important to have available, to the designer, runway utilization statistics which include combinations of runways that are used in IFR and VFR conditions. In addition, any conflicting traffic patterns which occur between primary and secondary airports within the terminal area should be noted. One source of runway information that was used during the Reference 1 study is the airport diagram which is contained in instrument approach charts.

2.2 TERMINAL AREA ROUTE STRUCTURES

An indication of the existing VOR route structure can be obtained from IFR charts of the route structures and instrument approach procedures from the terminal area. Information on preferred routings including fixes and routes that are used for arriving and departing traffic should be obtained. In addition, the primary radar vector routes to and from the airport for the most frequently used arrival and departure runways should be identified. The nominal radar vector paths should be obtained along with identification of the maneuvering airspace that is used by the controllers for traffic control purposes. Differences between the terminal route structures for jet and propeller driven aircraft should be noted. Finally, all significant fixes, intersections or waypoints that are

Table 1 Terminal Area Data Requirements

- AIRPORT DATA
  - Primary Airport
    - Runway Layout
    - Runway Utilization
  - Satellite Airports
    - Runway Layouts
    - Runway Utilization
    - Conflicting Traffic Patterns
- EXISTING TERMINAL ROUTE STRUCTURES
  - Fixes, Intersections, Waypoints
    - Latitude and Longitude
    - Altitude of Traffic
  - Fix Utilization
  - Holding Airspace
  - Maneuvering Airspace
  - Jet and Propeller Aircraft Routes
- RESTRICTED AIRSPACE AND PROBLEM AREAS
  - Restricted Airspace Areas
  - Noise Sensitive Areas
  - Noise Insensitive Areas (rivers, lakes, etc.)
  - High Terrain
  - Minimum Vectoring Altitudes
- TRAFFIC DATA
  - Origin - Destination City
  - Number of Flights
  - Time of Flights
  - Type of Aircraft
  - Bearing and Distance to Origin - Destination
- AIRCRAFT DATA
  - Climb - Descent Data
    - Distance vs Altitude Profiles
  - Cruise Data
    - Time Penalty vs Altitude
    - Fuel Penalty vs Altitude
- WORKING MAPS
  - Airports and Runway Patterns
  - Current Fixes
  - Latitude - Longitude Grid
  - Scaled to Include 45-60 nm from Primary Airport
- VERTICAL PROFILE CHARTS
  - Distance vs Altitude Graphs
  - Nominal Climb or Descent Profiles

used as altitude restriction points or route turn points in the existing VOR/radar vector route structure should be identified. The latitude, longitude and altitude of these points should be recorded along with the nominal altitude range of traffic which overfly these points. This data will be used for data processing purposes in the evaluation of the RNAV terminal area route structure.

2.3 SPECIAL RESTRICTIONS AND PROBLEM AREAS

Areas within the terminal airspace which are restricted for any reason should be noted. Such areas would include restricted airspace, noise sensitive areas and areas of high terrain. In addition, noise insensitive areas such as rivers, lakes, bays and oceans should be noted so that noise abatement procedures can make use of these areas. Finally, areas within the terminal area that are lacking in navigation, communication or radar coverage should be noted. Such areas would include unusable VOR radials. One useful source of this information is the minimum vectoring altitude chart found in the terminal ATC facility.

2.4 TRAFFIC DATA

Before the terminal route design procedure can be initiated, it is important to know the characteristics of the traffic which uses the terminal area in question. This data must include the destination city for departures, and the city of origin for arriving traffic. In addition, it is necessary to know the number of flights per day and the type of aircraft that are used. In order to develop an optimum RNAV route structure it is also necessary to determine the great circle bearing to the destination city, or from the originating city. The knowledge of this bearing angle permits the alignment of the terminal area routes to the traffic flow. One additional type of information is desirable in the terminal area traffic sample. This information concerns the range of typical cruise altitudes that are used by the aircraft in the enroute segment of flight. The approximate cruise altitude is useful in determining whether aircraft will be using the high or low altitude route structure. In general, propeller driven aircraft are more likely to use the low altitude structure, and jet aircraft with stage lengths in excess of 200 nm will usually use the high altitude route structure. The source of information that was used in the Reference 1 report for the traffic sample was the Official Airline Guide, North American Edition. This document was supplemented by information obtained from the terminal control facility on general aviation traffic that use the terminal area. Another source of information that may be more readily available to the airspace designers is flight data strips from a representative 24-hour period.

2.5 AIRCRAFT DATA

In order to evaluate the route structures that are produced and compare these route structures to existing flight paths, aircraft data is used in a terminal area evaluation computer program. Aircraft performance data such as standard climb and descent profiles are used by this program. In addition, cruise penalty tables are used to compute time and fuel penalties incurred by aircraft restricted to altitudes other than optimum cruise altitude. A discussion of this evaluation program and the data requirements are contained in Section 4.3 of this report and in Appendix A.

2.6 WORKING MAPS

One basic design tool that is indispensable in constructing existing flight paths and in developing new RNAV flight paths, is a good, scale, working map of the terminal area airspace. This map should contain airport runway patterns, currently used intersections and fixes, and a latitude-longitude grid. Also, it should cover the area within 45-60 nm of the primary airport in the terminal area. An example of a New York area map which was used during the Reference 1 study is shown in reduced form in Figure 2. In producing terminal route designs it is not unusual to use several of these maps throughout the design process. They are useful in locating existing high and low altitude route structures and radar vector paths to the active runway, displaying the great circle traffic data, developing the new RNAV route structures and numerous other interim steps between starting and finishing the route design procedure. The use of these working maps provides assurance that all charts that are developed are compatible in size, scale, and geographic coordinates.

2.7 DISTANCE-ALTITUDE PROFILES

A design tool which is effective in producing user beneficial vertical flight profiles is the distance-altitude profile diagram. In this diagram the vertical axis displays route altitude and the horizontal axis displays distance along the route from the runway. Superimposed on the chart is a climb or descent profile which represents the desired vertical envelope. An example of the climb and descent chart is shown in Figures 3 and 4, respectively.

When a candidate design is completed, each route is sketched out and plotted on one of the climb or descent charts. The route turn points and altitude restriction points are plotted on the chart and the altitudes of the route at that point are located along the horizontal axis. The altitude at each point can be compared to the desired profile and adjustments may be made to improve the vertical profile characteristics of the route. Intersections with other terminal area routes are located along the horizontal axis. The altitude of the intersecting route is plotted at that point on the vertical axis and conflicts in altitude may be observed when the intersecting route altitude and the altitude of the route under consideration overlap. This case is demonstrated on Figure 5 at Point A. Such a conflict point calls for an adjustment to one route altitude or ground track so that procedural separation may be assured.

In fairly simple terminal areas this procedure is relatively straightforward and may be necessary for only a few routes which intersect. In metroplex areas the number of route intersections is generally much greater than in a simple terminal area and many potential conflict areas may occur. In addition, in a metroplex areas, a change in one route may have a "domino" effect causing a series of altitude changes or ground track changes on several other routes. Nevertheless this procedure provides for a very thorough evaluation of the altitude profile of a route during the design process.

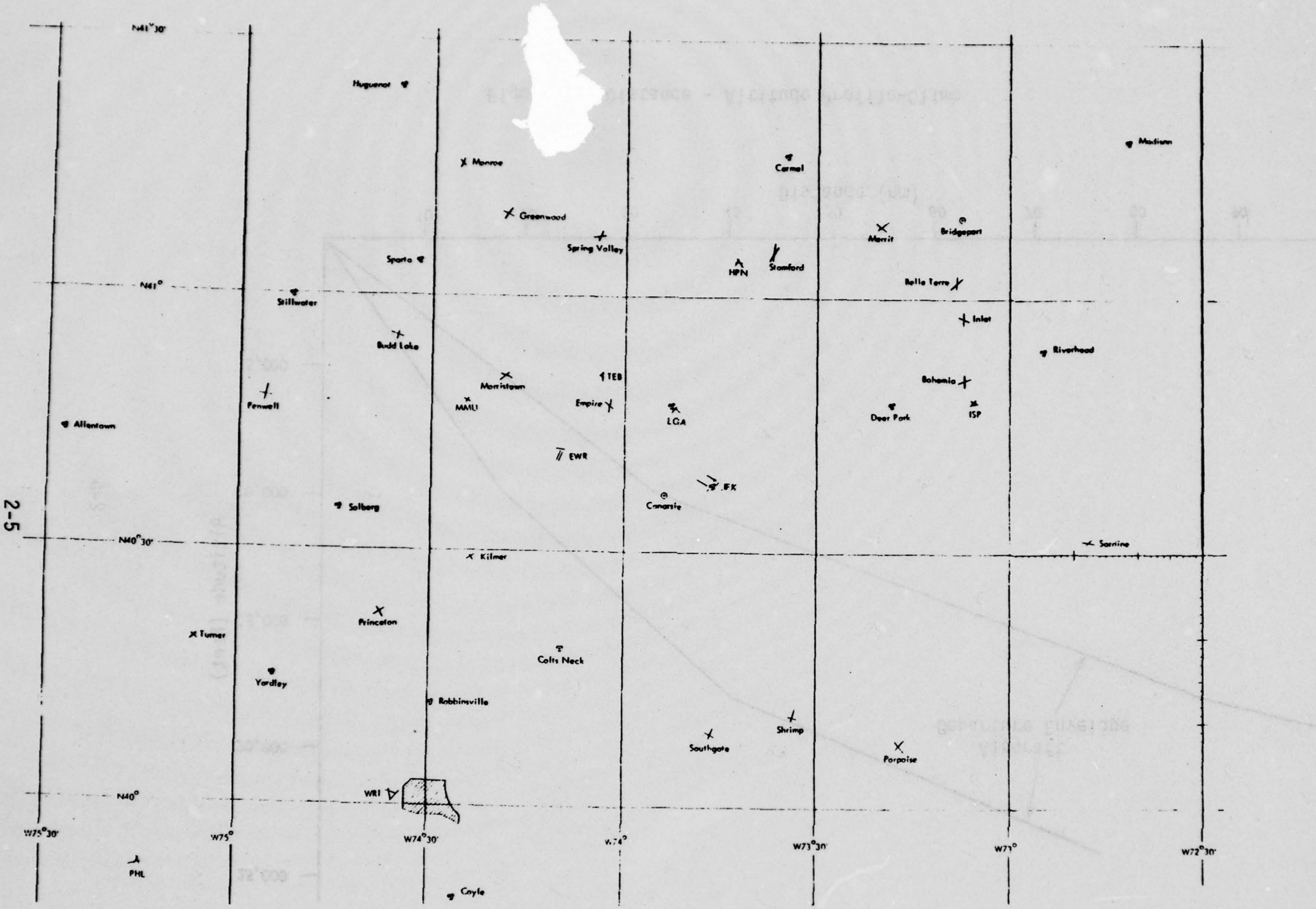


Figure 2 Scale Working Map of New York

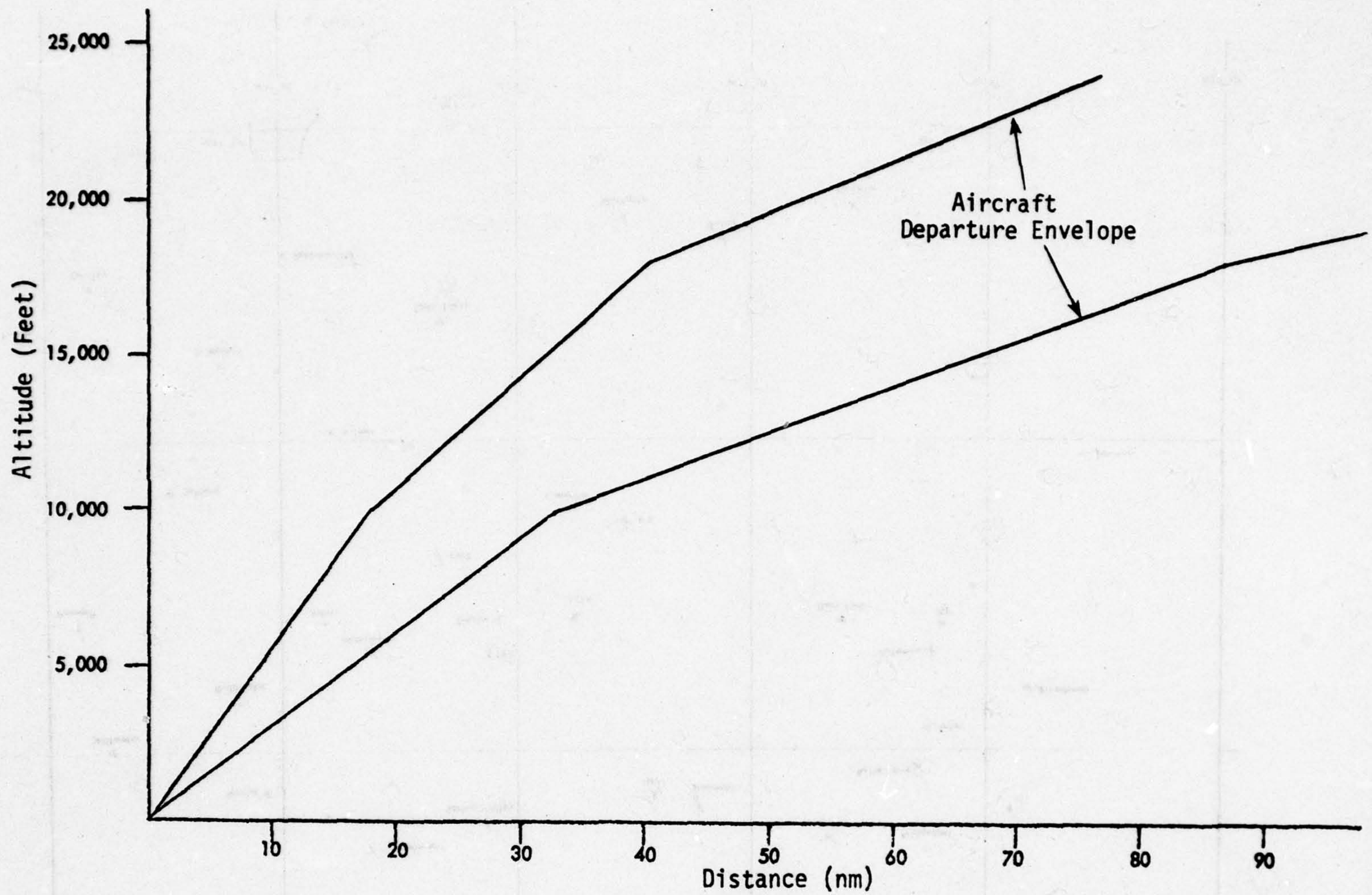


Figure 3 Distance - Altitude Profile-Climb

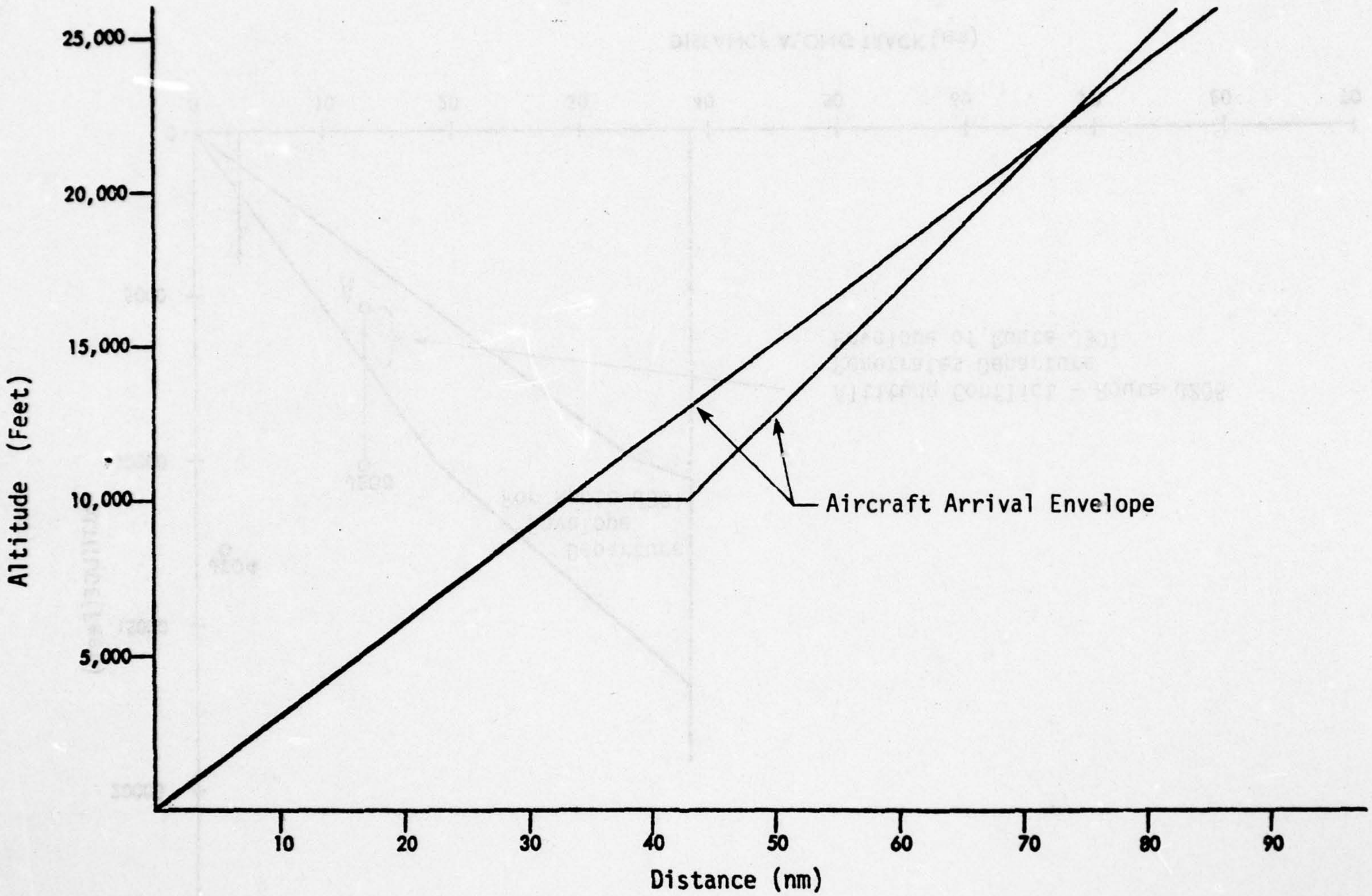


Figure 4 Distance-Altitude Profile-Descent

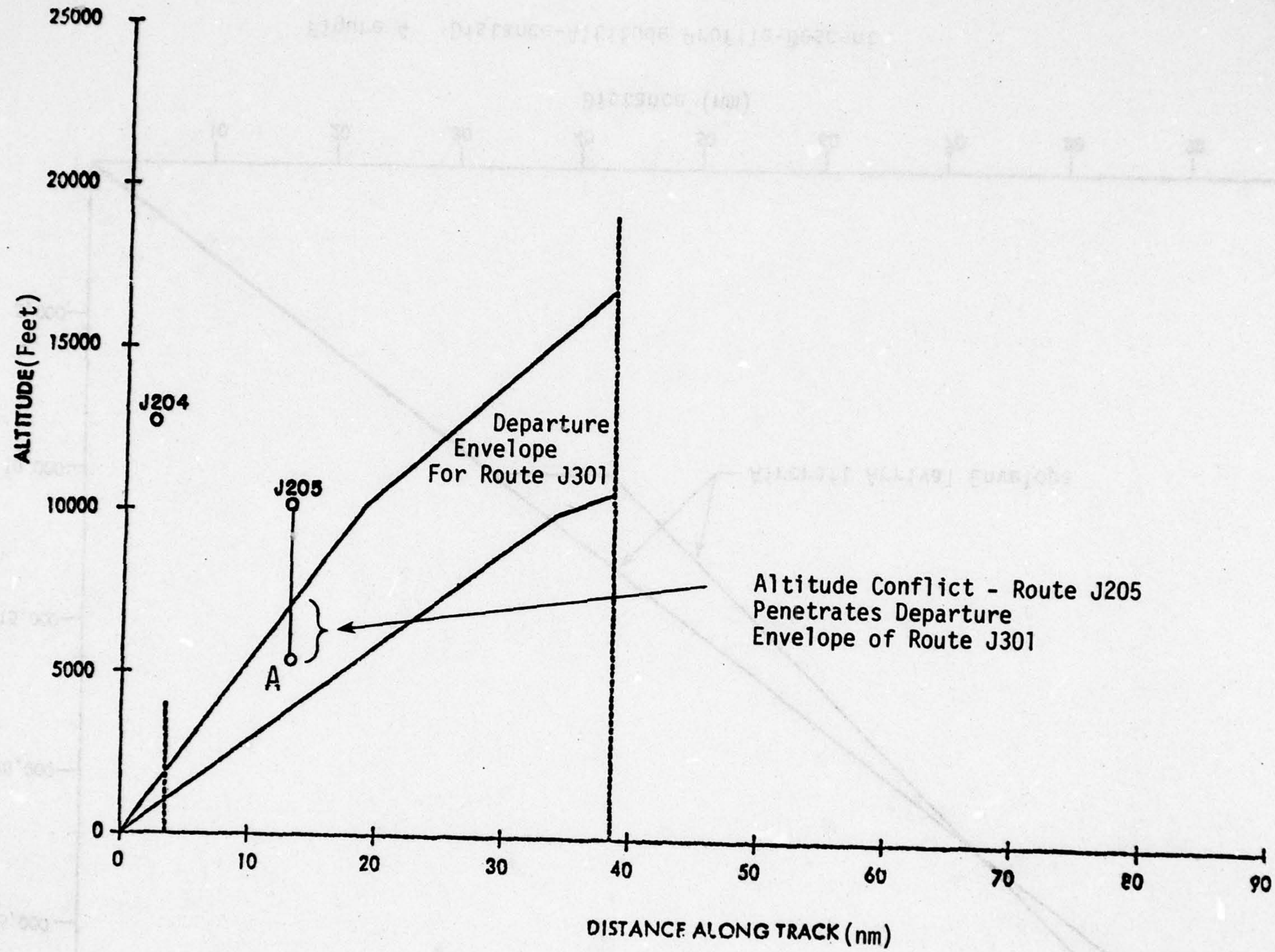


Figure 5 Example Altitude Conflict

2.8 SUMMARY

A comprehensive data base of terminal area geography, routes, traffic and operating restrictions is required to produce satisfactory terminal area RNAV route structures. Some of this data is used in data processing software for route design and evaluation purposes. Other parts of the data are used for more subjective terminal area considerations. More discussion of these subjective design considerations is contained in Section 4 of this report.

The design tools that are used in the route design process are primarily intended to develop the candidate terminal route structure in both the horizontal and vertical dimension. These design tools provide an effective means to accomplish this function.

3.0 DATA PROCESSING PROGRAMS

During the terminal area design study program described in Reference 1, a number of data processing design tools were developed. These design tools are discussed in detail in Appendix A. In the following paragraphs a general description of the purpose of the program is presented. A description of the input data requirements and the program output are also described.

3.1 PROGRAM TRPUN

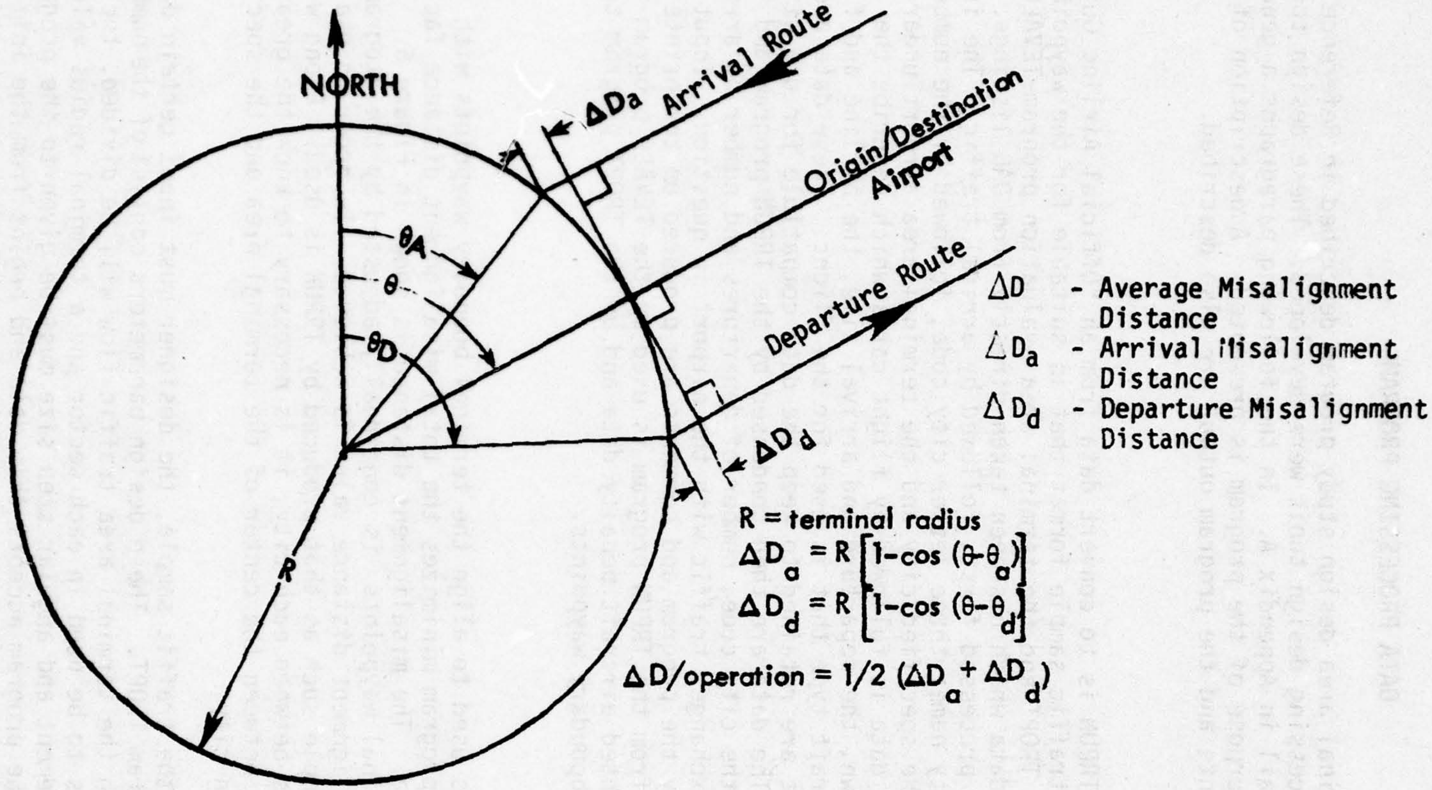
The purpose of TRPUN is to convert data from an "Official Airline Guide" (OAG) format into a traffic sample format that is suitable for the waypoint optimization program TROPT and the terminal area evaluation program TEVALP. The program accepts data which has been taken directly from OAG listings. Departure traffic is processed first, followed by arrival traffic. The input data contains the city name, three letter city code, followed by the number of flights between the specified city and the terminal area airport under consideration. This data is followed by flight cards which describe the days of the week flown, the departure and arrival time, the airline and flight number, and the aircraft type that is used for the flight. These data are not used by TRPUN but are retained to keep the data compatible for use with the TRSRT program. The data are then condensed by the TRPUN program and the output simply lists the city code, number of departures and number of arrivals for each city that exchanges traffic with the airport in question. Input data errors are flagged by the program and comments are produced on the printer output. The output from the TRPUN program is used by the TEVALP program to produce traffic weighted aircraft penalty data and by the TROPT program to locate the terminal boundary waypoints.

3.2 PROGRAM TROPT

Program TROPT is used to align the terminal boundary waypoints with the traffic flow. This program minimizes the total misalignment distance factor for the terminal area. The misalignment distance is shown in Figure 6. The location of the terminal waypoints is continually adjusted by the program until a minimum misalignment distance value is achieved. In order to use this program a traffic sample such as that produced by TRPUN is used. Along with the number of flights between each city, it is necessary to know the great circle bearing angle between the center of the terminal area and the specified origin or destination city.

In addition to the traffic sample, the designer must input certain design parameters into program TROPT. These design parameters consist of the number of sectors into which the terminal area traffic flow will be divided, the number of boundary waypoints to be used in each sector and a terminal radius value. An alignment angle increment and angular step size must be given to the progam for a starting point. The program accepts this data and begins from the initial alignment point and calculates the total misalignment distance for the terminal area. Then waypoints are adjusted in an iterative manner to achieve a minimum misalignment distance value. Experience with this program has shown that more than one minimum solution is possible with different initial alignment angles. Consequently, the program is restarted at various alignment angles so that an overall minimum value can be achieved.

The output of TROPT produces a candidate sector alignment for the terminal area. Specific outputs include the intermediate misalignment distance for each initial alignment angle, the minimum misalignment distance, the waypoint locations



ΔD - Average Misalignment Distance

ΔD_a - Arrival Misalignment Distance

ΔD_d - Departure Misalignment Distance

R = terminal radius

$$\Delta D_a = R\left[1-\cos\left(\theta-\theta_a\right)\right]$$

$$\Delta D_d = R\left[1-\cos\left(\theta-\theta_d\right)\right]$$

$$\Delta D/\text{operation} = 1/2\left(\Delta D_a + \Delta D_d\right)$$

Figure 6 Misalignment Distance Geometry

and the locations of each of the arrival and departure segment boundaries for the candidate sector alignment. With this output the terminal designer can begin to develop a terminal route structure which is aligned with the traffic flow.

3.3 PROGRAM ASMBL

Program ASMBL is used to assemble the terminal area route structure from a waypoint data file and a route data file. Once a candidate route design has been completed, each turnpoint and altitude restriction point in the design is given a waypoint number. The latitude, longitude and altitude of this waypoint are recorded in the waypoint data file. Then a route data file is created. This file contains the route number and the number of waypoints in the route followed by the sequence of waypoint numbers that comprise the route. The waypoint numbers are listed in order starting at the airport and extend to the terminal boundary. This order is used for both arrivals and departures. The program then assembles the data from the two files to produce a single file that contains the route numbers and the number of waypoints in the route followed by the latitude, longitude and altitude range for each of the waypoints.

3.4 PROGRAM TMALST

The TMALST program is used to check the output data from the ASMBL program for errors. The output of TMALST can be directly compared to the route structure maps. The data that is produced by the TMALST program is an input card image followed by the distance between waypoints, route segment bearing, permissible altitude range and the vertical path angle between waypoints. When this output data matches the route structures shown on the maps, then a permanent route file is created. This file is used for terminal area evaluation purposes.

3.5 PROGRAM TEVALP

Program TEVALP is the terminal area user evaluation program. In this program the route data, traffic data and aircraft data are used to produce route length and altitude restriction penalties associated with the aircraft operating over the terminal area route structure. The program computes the time and fuel penaltities of four aircraft types using the specified terminal routes. The program may be run any number of time to evaluate additional aircraft types. The penalty from the terminal misalignment distance is included in the output. The program also produces error messages on route segments where the aircraft is unable to achieve the required climb or descent altitude in the distance between the given waypoints. In addition the program will produce an output of time and fuel penalties on each route segment where the aircraft is held below its handbook climb or descent profile. This output is very useful in determining route segments that contribute significantly to aircraft penalties in terminal area operations.

3.6 PROGRAM TACOMP

Program TACOMP is the terminal area comparison program. This program accepts data from two TEVALP ouputs which utilize the same aircraft but different terminal route structures. Program TACOMP compares the time and fuel penalties of each of the route structures and produces benefit or penalty data for each aircraft type. Comparison values are given for arrivals, departures and the average per operation benefit or penalty.

3.7 PROGRAM TRSRT

The TRSRT program is used to provide a quantitative measure of the traffic flow which can be used for determining controller workload in each arrival or departure sector of the terminal area. This program uses the OAG traffic data and sorts this data into one hour segments for a 24 hour period. Thus for each hour of the day the traffic over each terminal arrival or departure sector can be obtained. In addition to collecting the traffic into one hour segments, the program also lists the flight times, the city and city codes, the airline and flight number, and the type of aircraft for each arrival or departure in the sector.

3.8 SUMMARY

The seven data processing programs that are described in this section are very useful in developing and evaluating terminal area route structures. All of these programs are not required to produce terminal area evaluations. Some of the programs are included for the convenience of the designer while others are necessary for design and evaluation. Programs ASML, TRPUN, TRSRT and TMALST were developed to aid in assembling data, correcting errors and converting the data into more useful formats. Program TROPT is useful for determining optimum waypoint locations. Program TEVALP is very useful in determining terminal area user benefits and the TACOMP program is convenient for comparing terminal route structures.

Other design procedures could be automated to expedite the design process. A logical candidate for this is the vertical profile evaluation procedure described in Section 2.8. The automation of this procedure could save the terminal designer a considerable amount of time in assigning altitudes and evaluating the vertical profiles of the terminal routes.

4.0 TERMINAL AREA DESIGN PROCEDURES

The following paragraphs outline the procedures that are used in developing terminal area route structures for terminal area operations. A flow diagram of the design procedures is shown in Figure 7. Each element shown in the flow diagram is discussed in detail in subsequent sections of this chapter.

4.1 TERMINAL AREA DEFINITION

The first step in the terminal design procedure is to define the terminal area. The terminal definition includes the selection of the airports and the geographic area to be considered in the design.

4.1.1 Terminal Area Airports

The airports that should be considered include all facilities which have significant IFR operations. The level of significance may vary from area to area, but those airports with more than 5-10% of the total terminal IFR traffic should be considered as having a potential impact upon the terminal area traffic patterns. Existing terminal procedures may be used to determine whether the satellite traffic should be considered significant. When satellite airports have independent routes within the terminal area, their impact is usually significant. If satellite traffic is handled along the same routes as the primary airport traffic, then the satellite airport traffic may not need to be considered separate from the primary airport traffic.

4.1.2 Terminal Traffic Flow

The next step in the design procedure requires a decision as to which runway patterns will be used to develop the route structure. In most terminal areas it is sufficient to investigate two or three runway utilization configurations during the initial design procedure. Often these two or three traffic flow patterns will account for a high percentage of the total terminal IFR operations. However, in some metroplex ares, such as New York, and at airports which have complex runway structures, such as Chicago O'Hare, it may be necessary to consider preliminary route structures for more than three traffic flow directions.

The procedure that is used in developing the terminal designs is to select runway combinations for initial route development that are representative of a high percentage of the IFR operations. The basic flow patterns into and from the terminal area are based on these runway patterns. After satisfactory designs have been developed using these runways, then the lesser used runway patterns are analyzed to find any additional problem areas. Modifications to the basic terminal design may or may not be required from these considerations of the lesser used traffic flows and runway combinations.

4.1.3 Terminal Boundary - Single Primary Airport Area

The remaining task associated with terminal area definition is fixing the location of the conceptual terminal boundary. This boundary represents a convenient separation of terminal and transition area airspace for the purposes of

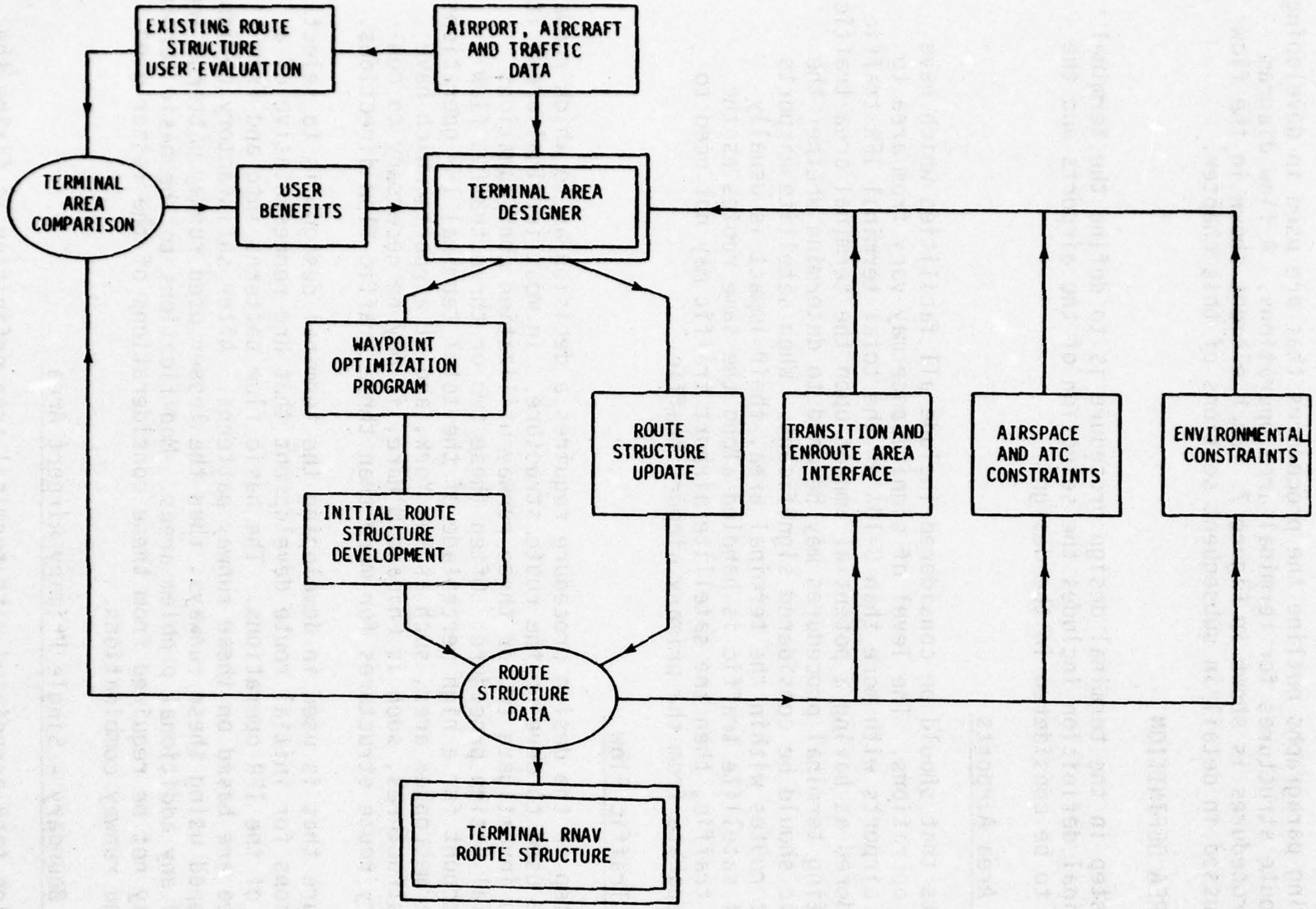


Figure 7 Terminal Area Route Design Process

route design. It has no meaning insofar as actual ATC operations or control jurisdiction. For terminal areas that have a single primary airport, it is usually sufficient to describe the terminal area as a 45 nm circle that is centered at the airport. The radius of the terminal area may be made larger or smaller if desired. However, the boundary should be located at least 10-15 nm beyond the extent of existing arrival feeder fixes. If operational considerations make it desirable to use some point other than the airport as the center of the terminal area, then the center may be relocated. However, the terminal boundary should still be located several miles outside the current feeder fixes.

4.1.4 Terminal Boundary - Metroplex Areas

The location of terminal area boundaries in metroplex areas should be based upon the location of the existing feeder fixes of the major airports in the metroplex area. A circle is drawn to enclose all of the existing feeder fixes. Then a larger circle with a radius that is 10-15 nm greater than the original is drawn using the same center location as the original circle. This larger circle thus becomes the conceptual terminal area boundary for the metroplex area. Operational considerations may make it desirable to modify this terminal area boundary. One situation which may cause this to happen is overlapping terminal area boundaries. This situation may occur in adjacent metropolitan areas such as the New York-Philadelphia area and other congested areas in the northeastern part of the United States. Usually the terminal boundary circle should not have a radius that exceeds 60 nm.

4.2 CURRENT TERMINAL ROUTE STRUCTURES

Once the extent of the terminal area has been defined, the existing terminal route structures should be drawn on the working maps. The location of all route turnpoints and altitude restriction points are drawn to scale on the map. Routes from the satellite airports may be included on the same maps if their route structures are fairly simple. However, if the satellite routes are complex, then it is useful to develop them on separate charts. Nominal routes should be drawn in the airspace from the runway to the terminal area boundary for each of the runway patterns under consideration.

When all of the route turnpoints and altitude restriction points have been identified, the latitude and longitude coordinates should be recorded along with the expected range of aircraft altitudes over these points. These data should be placed in a fix or waypoint file for future data processing. The software programs ASMBL and TMALST may be used to develop the route files and to check the correctness of the entries in the route file. A complete description of these programs and the formats of their input and output data is contained in Appendix A. By a convention developed during the Reference 1 study, route numbers from 1-99 and 101-199 represent existing arrival and departure routes, respectively. The new RNAV route structures are assigned numbers from 201-299 for arrivals and 301-399 for departures.

4.2.1 Philadelphia VOR/Radar Routes

An example of the VOR/radar vector terminal area route structure for Philadelphia is shown in Figure 8. Satellite airport traffic is not considered

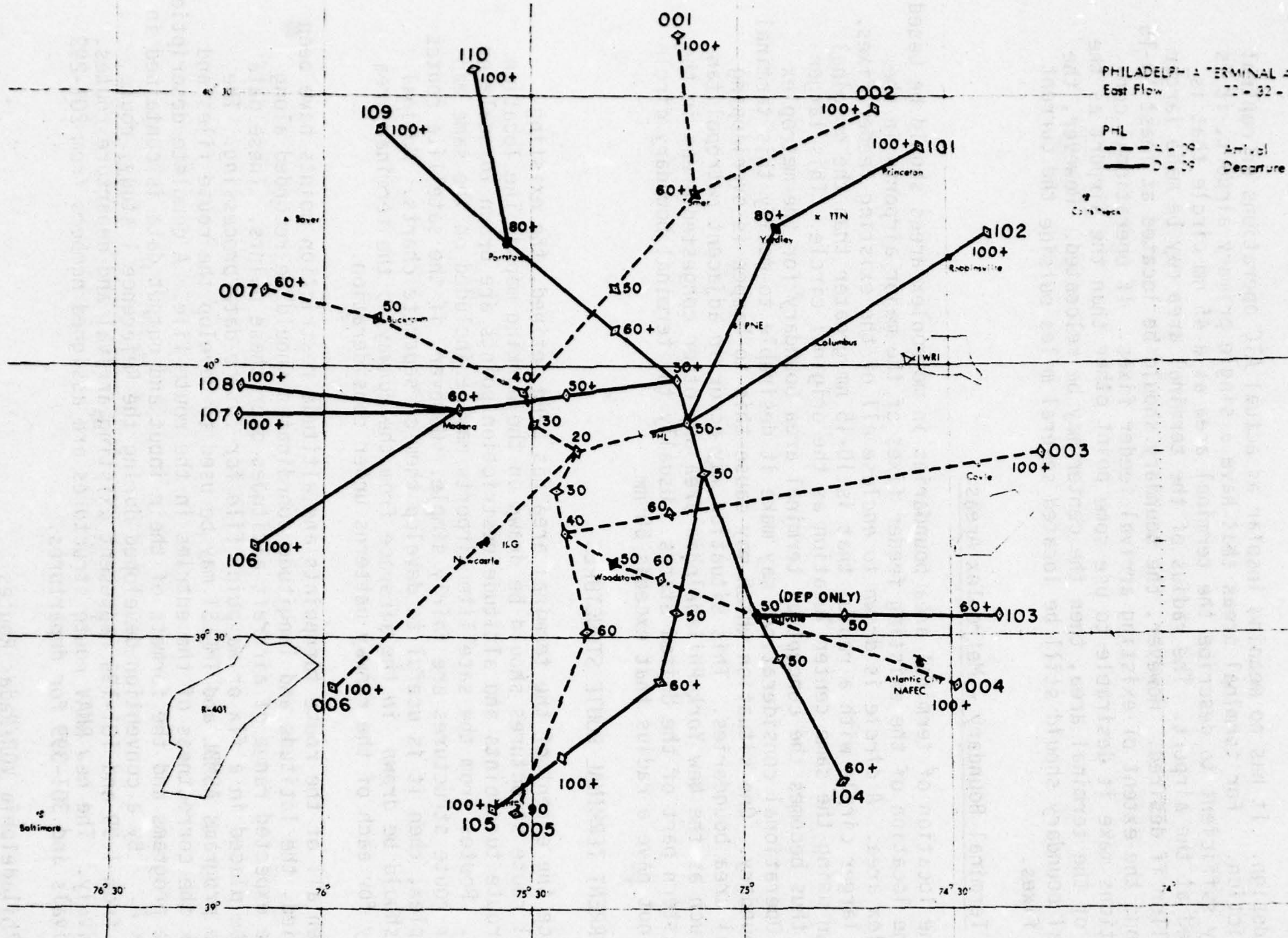


Figure 8 Philadelphia Terminal Area - VOR/Radar Vector Route Structure - East Flow

in this diagram. Note that different line characteristics are used to distinguish between arrival and departure routes. On the working maps color discrimination may be used to represent arrivals and departures and traffic from various terminal airports. Note also that altitudes are given at each route turn point and at altitude restriction points.

4.2.2 New York VOR/Radar Routes

In Figure 9 the New York terminal route structure is shown. Obviously the route structure is considerably more complex than that at Philadelphia. Line symbol discrimination is used for arrivals and departures from the three major airports. Color discrimination on the working maps is considerably more effective than line symbol descrimination in separating these complex route structures. Altitude restrictions are shown at each significant point along the route. These altitudes are used so that procedural separation is available on all routes. Note that only the nominal paths to the airports are shown. Maneuvering airspace requirements are considered in subsequent analyses.

4.3 EVALUATION OF CURRENT ROUTE STRUCTURE

Once the current terminal route structure has been assembled and put into data files, the terminal routes can be evaluated from a user standpoint. This is accomplished by using the terminal area evaluation program called TEVALP. This program combines the terminal traffic data, aircraft performance data and the route data to produce output data which describes aircraft time and fuel penalties associated with using these routes. The three types of data that are computed are as follows:

- traffic weighted terminal area route lengths
- traffic weighted misalignment distance
- altitude restriction penalties

The term traffic weighted means that in the evaluation, each route is assigned a weighting factor which is proportional to the amount of traffic on that route. The use of the traffic weighted average is superior to using a direct arithmetic average of route lengths and misalignment distance. This traffic weighted averaging procedure provides assurance that the computed penalties reflect the traffic characteristics of the terminal area under consideration.

4.3.1 Evaluation Data Example

An example of the output that is obtained from the TEVALP program is shown in Figure 10. The terminal area calculations are performed for the arriving traffic followed by departing traffic. The first output value shown in Figure 10 is the traffic weighted route length. This number is computed in nautical miles and represents the average distance flown by all arriving (or departing) aircraft. The second value computed is the average misalignment distance per arrival (or departure). The misalignment distance concept is discussed in Section 3.2. This number reflects the alignment of the terminal arrival (or departure) sectors with traffic flow. A high value of misalignment distance

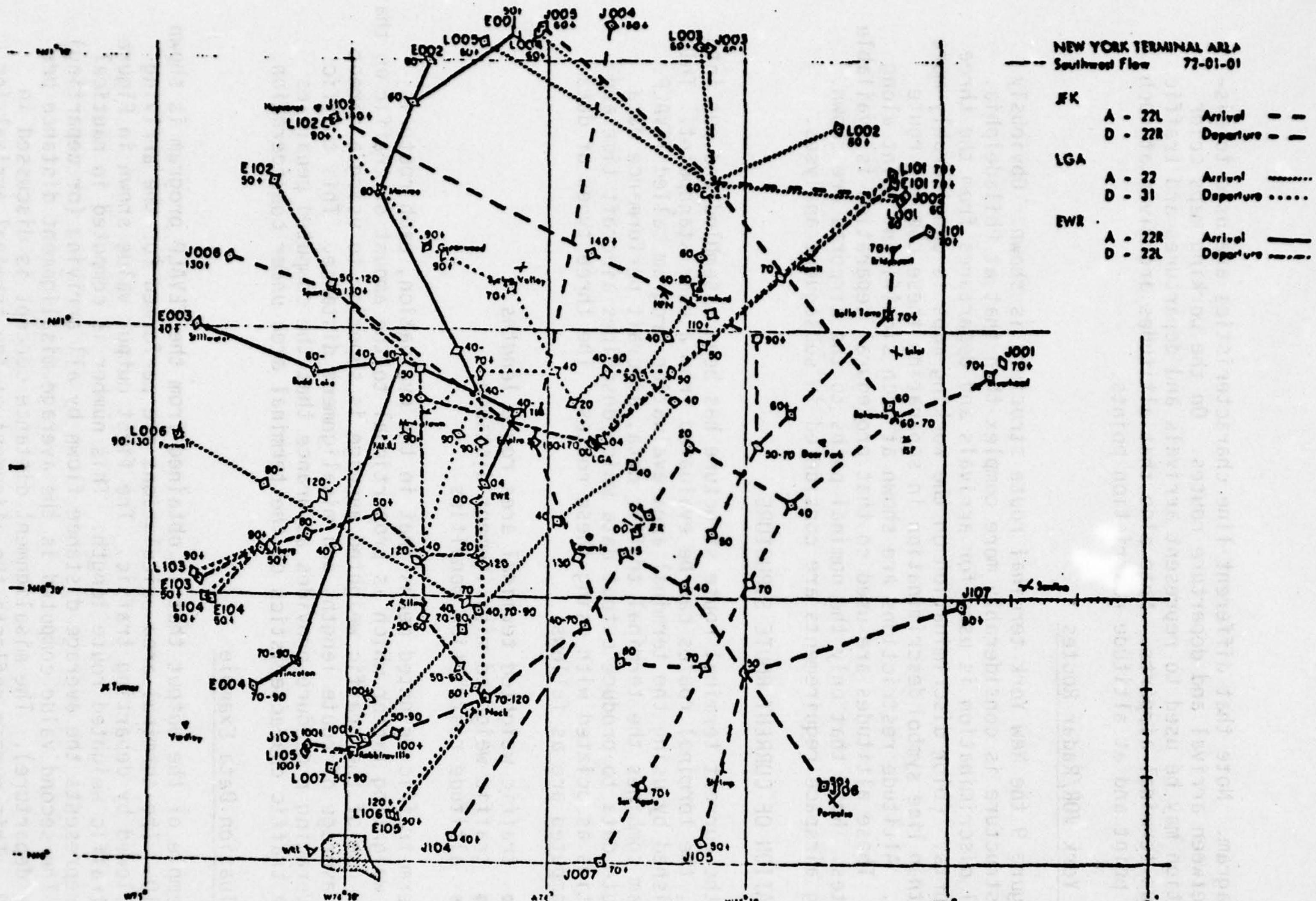


Figure 9 New York Terminal Area-VOR/Radar Vector Route Structure-Southwest Flow

```
copy,tape2
82-32-07   77/12/20.               Identification, date
     52.06         178             Arrival route length, traffic
      1.28                         Arrival misalignment distance
DC-9             37.3      .353    DC-9 fuel, time penalty(arrivals)
B727            189.3      .407    B727  "     "     "      "
DC-8            314.2      .353    DC-8  "     "     "      "
B747            524.9     1.607    B747  "     "     "      "
     54.22         178             Departure route length, traffic
       .48                         Departure misalignment distance
DC-9             16.6      .204    DC-9 fuel, time penalty(departures)
B727             26.5      .224    B727  "     "     "      "
DC-8             55.4      .195    DC-8  "     "     "      "
B747            126.9      .263    B747  "     "     "      "
 END OF INFORMATION ENCOUNTERED.
/
```

(Fuel in pounds, time in minutes, distance in nautical miles)

Figure 10 Terminal User Evaluation Data

indicates that the route structure is not aligned well to traffic flow. A low value (less than 2.0 nm) indicates a reasonable alignment exists.

The last portion of the program computes the time and fuel penalties associated with four types of aircraft using the terminal routes. From aircraft data tables, penalties are computed whenever the aircraft is held below its handbook descent (or climb) value. The penalty is computed by using speed and fuel burn differences at the restricted altitude as opposed to a typical cruise altitude. On each segment that a penalty is incurred, a message is written on the TEVALP output. These penalty values are useful in determining which route segments contribute significantly to the overall aircraft penalties.

4.3.2 Unattainable Altitude Message

If the altitude requirments shown on the route structure cannot be achieved according to the data in the standard descent (or climb) tables, then a message is printed on the output. This message indicates that the altitude is unattainable based on the tabular values. The additional distance required to achieve the specified altitude is printed also. Generally if this distance is less than one mile, no modification of the altitudes is made. However, if several additional miles are required to achieve the profile, then the altitudes should be checked for possible errors. The departure data is produced by the program subsequent to the arrival data. Its format is similar to the arrival data.

At the present time the aircraft data file that is used by TEVALP is capable of computing time and fuel penalties for eight types of aircraft. These aircraft are:

DC-9	DC-10
B-727	F-28
DC-8	Lear Jet 25
B-747	FH-227

Data for other aircraft can be developed from aircraft performance data.

The user related terminal area data should be computed for each traffic flow at each primary and satellite airport for which route data has been processed. These data will be used for subsequent comparisons with similar data that are computed using the new RNAV based route structures.

4.4 OPTIMAL TERMINAL BOUNDARY WAYPOINTS

Before the terminal design procedure can continue, it is necessary to consider some ground rules that were developed in the Reference 1 study concerning terminal area traffic flow. These ground rules apply to the routes used by aircraft using the low altitude and high altitude RNAV route structures.

4.4.1 High Altitude Traffic

High altitude traffic is considered to be all turbojet aircraft which has a stage length equal to or greater than 200 nm. High altitude traffic is assumed to arrive at the terminal area in designated arrival sectors and depart

the terminal area through designated departure sectors. These sectors generally extend from a point that is approximately 25 nm from the airport to the conceptual terminal boundary. The sectors alternate between arrival and departure areas around the terminal boundary. The arrival and departure sectors do not have to be of equal size. Typical sector configurations in the Reference 1 study made use of either eight or ten sectors in most terminal area route structures in that study.

4.4.2 Low Altitude Traffic

Low altitude traffic within the terminal area is considered to be all piston and turboprop operations and turbojet operations with stage lengths less than 200 nm. Low altitude traffic is not constrained to remain within the arrival and departure sectors. Generally the low altitude traffic is assumed to arrive at (and depart from) the conceptual terminal boundary at a point that lies on a direct bearing between the airports in question or at some point that is more operationally suitable based upon the low altitude RNAV routes that connect the cities. The low altitude traffic is assumed to have reached or nearly reached its cruise altitude within the confines of the conceptual terminal boundary. Thus all route transitions for low altitude traffic occur within the terminal airspace. In metroplex areas it is sometimes necessary to constrain the low altitude traffic to the appropriate arrival or departure sector until they are clear of high altitude traffic from other airports. When situations like this occur, the terminal entry and exit points for the low altitude traffic may not conform to those adopted for the less complex terminal areas.

4.4.3 Sector Description for Single Primary Airport Areas

The next task for the terminal designer is to determine the initial candidate locations for the terminal boundary waypoints. For the high altitude traffic this may be achieved through the use of the TROPT program. This program uses the terminal area traffic sample to minimize the misalignment distance of the terminal area. The designer must provide the program with some input parameters. The first parameter is the number of arrival and departure sectors to be used. Since the sectors are assumed to be alternating arrival and departure areas, an even number of sectors should be used. The second input parameter is the number of boundary waypoints in each sector. The third parameter is the terminal radius. The final input parameters are the sector alignment increment and an angular step size. The alignment describes the initial orientation of sectors with respect to true north.

With this information TROPT searches for a minimized value of misalignment distance. The program can be set up to restart at several initial alignment angle values so that an overall minimum can be obtained. This procedure is necessary because several local minima may occur before an absolute minimum misalignment distance is obtained. The angular increment is used to reset the alignment angle.

During the Reference 1 study it was observed that as a general rule the high density terminal areas like New York, Chicago, Atlanta, etc., had an eight

segment terminal area pattern, four arrival and four departure areas, while the medium-sized hub areas like Philadelphia, Denver (at that time), New Orleans, San Francisco and Miami had ten or more arrival and departure areas. A general pattern seemed to occur. That is, as the traffic density becomes larger the need to organize the airspace into fewer arrival and departure segments becomes apparent.

Generally it was found that in the medium density hub areas a ten sector terminal area provided satisfactory RNAV boundary waypoints. These sectors were divided into five arrival areas and five departure areas each containing two boundary waypoints. In the higher density terminals with one major airport, for example Chicago, an eight segment terminal area with three boundary waypoints per sector produced a satisfactory set of boundary waypoints.

In the Reference 1 study the terminal areas were referred to as an 8/3 or 10/2 terminal which describes the sectors and waypoints per sector. Other combinations such as 8/2 and 10/3 were evaluated in this study but 8/3 and 10/2 were generally found to produce more satisfactory route structures in the single major airport areas. It should be emphasized that the use of the same number of waypoints per sector is specified for the purpose of the TROPT program only. If it is operationally advantageous to add additional waypoints or to delete seldom used waypoints, then this may be performed by the terminal route designer. It should also be noted that TROPT produces candidate waypoint locations. The final location of the terminal boundary waypoints is established through consideration of terminal and transition area interface problems and other operational issues.

4.4.4 Sector Description for Metroplex Areas

In the Reference 1 study the boundary waypoint procedure had to be modified for the complex New York area. Each airport's traffic was used in the TROPT program. Eight and ten sector terminal areas with one waypoint per sector were evaluated using TROPT. The resulting boundary waypoints were plotted on a single working map. Adjustments in the waypoint locations were made to assure adequate separation between the terminal routes. This procedure produced an acceptable starting point for developing the New York route structure.

4.4.5 Selection of Arrival-Departure Sectors

The candidate waypoint locations from TROPT have one ambiguity problem. No differentiation is made between arrival and departure areas. The procedure which was used to resolve this ambiguity in the Reference 1 study compared the new terminal sectors with existing arrival and departure areas. The sector alignment which contained the greatest compatibility with existing operations was selected for route structure development. If for some reason, this procedure doe not produce satisfactory route structures, then the sectors may be reversed without affecting the misalignment distance associated with the terminal waypoint locations.

4.4.6 Example Waypoint Location Analysis

Figure 11 shows the output of the TROPT program for the Philadelphia terminal area. The first series of data show the initial alignment angle followed by the total misalignment distance for that configuration. It may be seen that several

number of terminal segments
number of waypoints per segment
terminal radius value (nm)
alignment angle increment (degrees)
initial step size (degrees)

```
? 10,2,45.,35.,8.
  349.3    0.0    8.0
  292.4    0.0    8.0
  277.1    0.0    8.0
  277.0    0.0    8.0
  277.0    0.0    8.0
  250.7    0.0    4.0
  250.0    0.0    4.0
  250.0    0.0    4.0
  250.0    0.0    4.0
  250.0    0.0    4.0
  245.4    0.0    2.0
  244.8    0.0    2.0
  244.7    0.0    2.0
  244.7    0.0    2.0
  244.6    0.0    2.0
  244.6    0.0    2.0
  244.5    0.0    2.0
  244.6    0.0    2.0
  244.6    0.0    2.0
  243.6    0.0    1.0
  243.6    0.0    1.0
  243.6    0.0
  358.9   35.0    8.0
  297.9   35.0    8.0
  278.1   35.0    8.0
  275.8   35.0    8.0
  275.8   35.0    8.0
  251.3   35.0    4.0
  249.7   35.0    4.0
  249.7   35.0    4.0
  243.3   35.0    2.0
  243.3   35.0    2.0
  241.6   35.0    1.0
  241.6   35.0    1.0
  241.6   35.0

  MINIMUM MISALIGNMENT DISTANCE VALUE =      241.64

   SEGMENT ANGLES
 50.0   71.0  104.0  175.0  203.0  231.0  266.0  287.0  308.0   23.0

   ARRIVAL(DEPARTURE) WAYPOINT BEARINGS
 55.2   65.8  121.8  157.3  210.0  224.0  271.3  281.8  327.0    5.0

   DEPARTURE(ARRIVAL) WAYPOINT BEARINGS
 79.2   95.7  132.0  196.0  239.8  257.3  292.3  302.8   30.5   43.5
```

misalignment distance

initial alignment angle (degrees)

step size (degrees)

minimum misalignment distance
for 0° initial alignment angle

minimum misalignment distance
for 35° initial alignment angle

CITY BEARING	NO. OF FLIGHTS	ARR-WPT BEARING	DEP-WPT BEARING
20.20	4	5.00	30.50
45.70	5	55.25	43.50
50.70	25	55.25	43.50
57.90	3	55.25	43.50
157.30	3	157.25	132.00
186.90	1	210.00	132.00
194.50	5	210.00	196.00
198.00	4	210.00	196.00
198.20	7	210.00	196.00
198.50	1	210.00	196.00
200.10	2	210.00	196.00
205.70	2	210.00	196.00
209.10	5	210.00	196.00
211.20	1	210.00	196.00
215.00	3	210.00	196.00
216.10	1	210.00	196.00
225.90	3	224.00	239.75
232.00	1	224.00	239.75
232.60	12	224.00	239.75
235.80	2	224.00	239.75
245.10	1	224.00	239.75
251.10	3	271.25	257.25
252.20	1	271.25	257.25
255.10	4	271.25	257.25
266.60	1	271.25	257.25
269.30	3	271.25	257.25
269.40	1	271.25	257.25
272.60	1	271.25	257.25
273.70	3	271.25	257.25
274.10	1	271.25	257.25
274.10	3	271.25	257.25
279.30	3	281.75	292.25
280.80	21	281.75	292.25
282.00	1	281.75	292.25
286.50	13	281.75	292.25
289.10	8	281.75	292.25
292.10	1	281.75	292.25
293.60	7	281.75	292.25
296.60	2	281.75	292.25
302.30	2	281.75	302.75
320.70	3	327.00	302.75
320.70	1	327.00	302.75
331.50	2	327.00	302.75
349.10	2	5.00	30.50

```
? stop
*TERMINATED*
```

Figure 11 Waypoint Optimization Data for Philadelphia

of the misalignment distance values are greater than the minimum value of 241.6 which was obtained with an initial alignment angle of 35 degrees. This situation arises because several local minima are often found before the overall minimum value is obtained.

The remaining output data is related to the final terminal area alignment. The initial alignment angle and minimum misalignment distance value are then repeated after all of the initial angles have been processed. The waypoint orientation with respect to true north is then printed followed by the arrival and departure sector boundaries. A nominal assignment of arrival and departure sectors is made by the TROPT program. This assignment may be reversed by the designer based on the considerations of Section 4.4.5.

The waypoint locations and sector boundaries for Philadelphia are shown in Figure 12. Note that the 10/2 design characteristic is shown. The waypoint locations that were produced for New York using the metroplex procedure are shown in Figure 13. Note that in some areas the arrival and departure waypoints are well aligned for the three airports while in other cases the waypoints almost overlap. In metroplex areas some adjustment of the waypoint locations will usually be necessary to achieve satisfactory route separation and compatible traffic flow areas. The waypoints shown in Figure 13 had to be adjusted considerably before a satisfactory route structure for New York was achieved.

4.5 EVALUATION OF CONTROLLER WORKLOAD

Once the boundary waypoint locations have been established, an assessment of peak hour controller workload can be made by using the TRSRT program. By using the traffic allocation output from TROPT, the terminal traffic data is sorted into several small files, each file containing the arrival or departure traffic for a corresponding sector. Each file is then processed by TRSRT. The output from TRSRT produces hourly summaries of traffic in the specified sector. Peak hour operation demand can be determined for each arrival and departure sector. If the peak hour operations for any one sector exceed some desired limit, then the designer may make adjustments in the boundary waypoint locations to distribute the traffic in a more satisfactory manner.

An example of the TRSRT ouput can be seen in Figure 14. The traffic is sorted by arrival or departure time. The output data shows the corresponding city and city code, the airline and flight number, and the aircraft type. Summaries of aircraft type are presented for each hour.

4.6 DEVELOP CANDIDATE RNAV ROUTE STRUCTURES

At this point in the design process the terminal boundary waypoints and arrival/departure areas have been identified. The next step is to develop the feeder fix locations (also described as low altitude arrival waypoints) for the arrival routes. This procedure is relatively straightforward in the single airport terminal area. In the metroplex area the problem is compounded by the need to develop feeder fixes for each airport. The feeder fix is assumed to be the last holding fix prior to making the approach. Thus, in metroplex areas, particular attention must be given to holding airspace requirements at the feeder fixes.

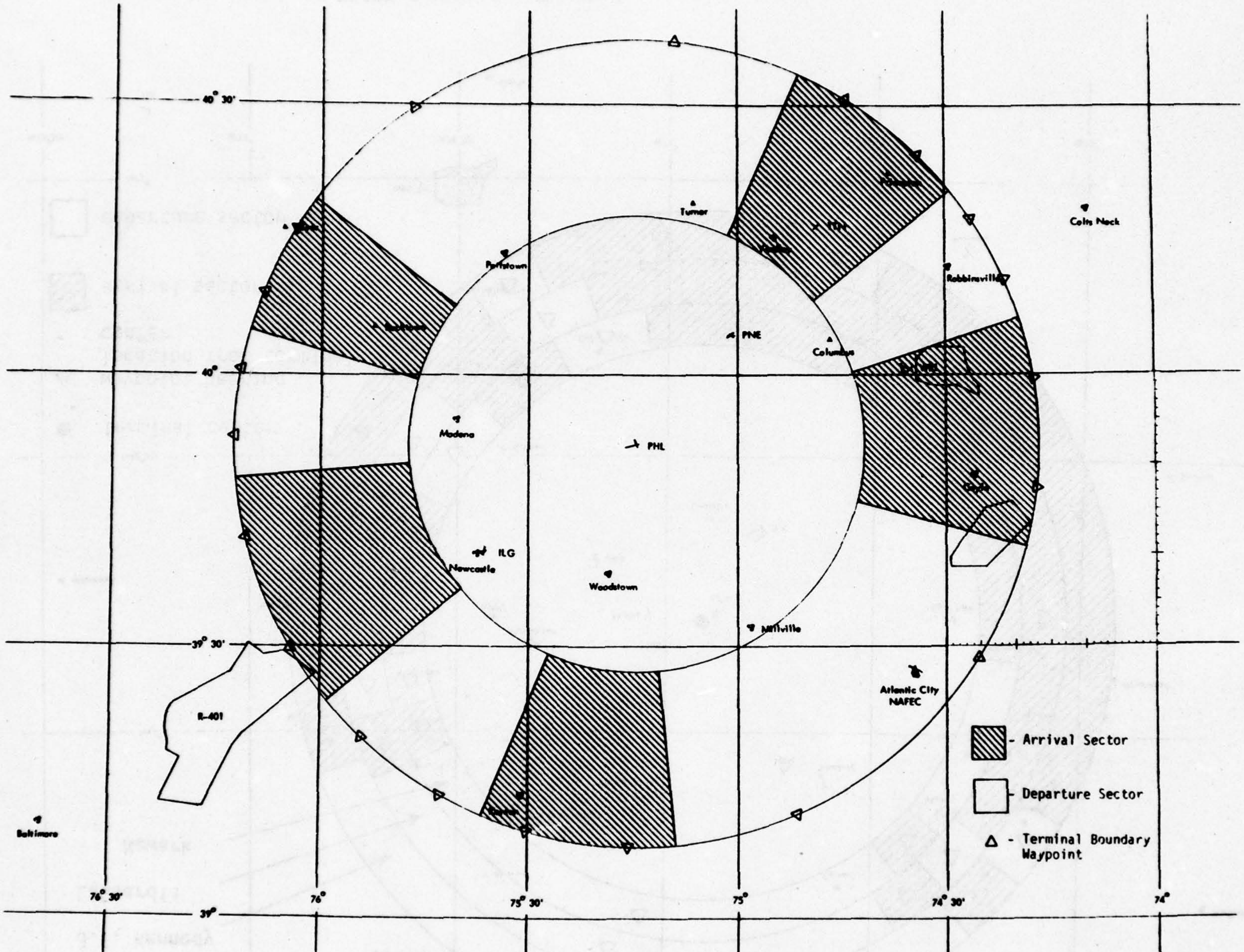


Figure 12 Map of TROPT Output for Philadelphia

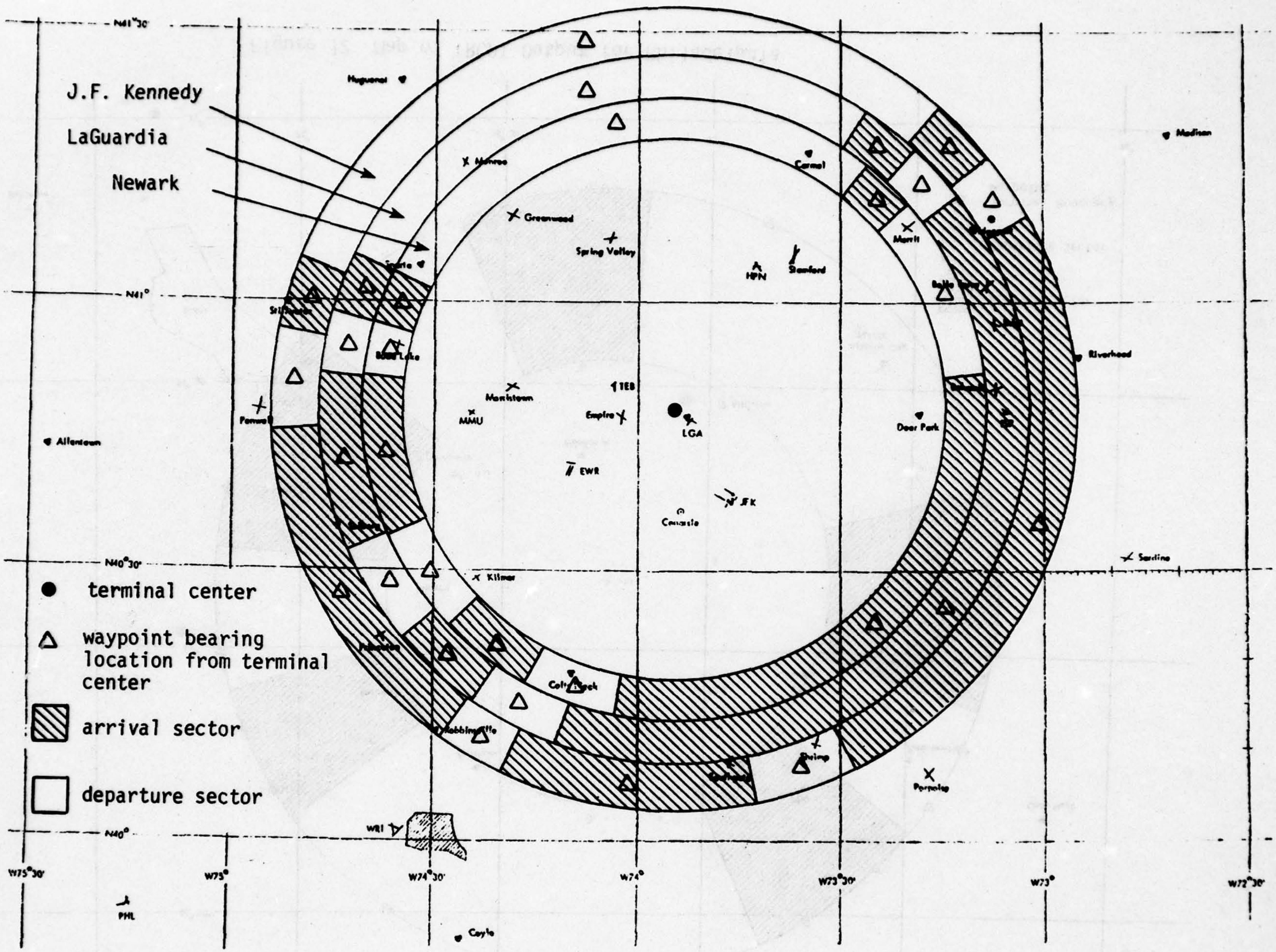


Figure 13 Map of TROPT Output for New York

```
TRAFFIC FOR TIMES BETWEEN  900 AND 1000

  TIME          ORIGIN                CODE  FLIGHT  AIRCRAFT

   913  BALTIMORE,MD                  BAL   AL 225    D9S
   923  CHICAGO,ILL                   CHI   DL 869    D9S
   944  ATLANTA,GA                    ATL   EA 688    727
   943  BUFFALO,NY                    BUF   AL 165    D9S

D9S   B11   DC9   727   72S   BE9   707   D10   L10   737   73S
  3     0     0     1     0     0     0     0     0     0     0

747   UNC
  0     0

TRAFFIC FOR TIMES BETWEEN 1000 AND 1100

  TIME          ORIGIN                CODE  FLIGHT  AIRCRAFT

  1002  DAYTON,OH                     DAY   TW 129    DC9
  1017  CINCINNATI,OH                 CVG   AA 429    72S
  1021  ATLANTA,GA                    ATL   DL 460    72S
  1047  CHICAGO,ILL                   CHI   AL 138    D9S

D9S   B11   DC9   727   72S   BE9   707   D10   L10   737   73S
  1     0     1     0     2     0     0     0     0     0     0

747   UNC
  0     0

TRAFFIC FOR TIMES BETWEEN 1100 AND 1200

  TIME          ORIGIN                CODE  FLIGHT  AIRCRAFT

  1105  BLOOMINGTON,IND               BMG   AL 646    BE9
  1127  DAYTON,OH                     DAY   AL 135    D9S
  1129  CHICAGO,ILL                   CHI   AA 238    707
  1140  AKRON/CANTON,OH               CAK   AL 151    D9S

D9S   B11   DC9   727   72S   BE9   707   D10   L10   737   73S
  2     0     0     0     0     1     1     0     0     0     0

747   UNC
  0     0

TRAFFIC FOR TIMES BETWEEN 1200 AND 1300

  TIME          ORIGIN                CODE  FLIGHT  AIRCRAFT

  1215  ATLANTA,GA                    ATL   EA 296    DC9

D9S   B11   DC9   727   72S   BE9   707   D10   L10   737   73S
  0     0     1     0     0     0     0     0     0     0     0

747   UNC
  0     0
```

Figure 14 Sorted Traffic Output Data from TRSRT

4.6.1 Feeder Fix Location

The candidate feeder fix locations in single airport areas are found by placing waypoints in the center of the arrival sector at a distance of 25 nm from the airport. This location may be adjusted for operational reasons if necessary. Considerations of such factors as terrain, satellite airport location, noise sensitive areas, navaid coverage, etc., can affect the final choice for the feeder fix placement.

The feeder fix is a merge point for traffic entering the terminal area in each sector. Both high and low altitude traffic pass over the feeder fixes. High altitude traffic arrives via the terminal waypoints in the appropriate arrival sector. Low altitude traffic is not constrained to remain within specified arrival and departure areas except in metroplex or other congested traffic areas where direct routes are not operationally practical. Low altitude arrival and departure traffic is generally assumed to enter or depart the terminal area on or near a great circle bearing between the origin and destination cities.

The traffic patterns from the feeder fix location to the terminal boundary remain unchanged regardless of the active arrival and departure runways. Traffic patterns inside the feeder fix circle change to accommodate the runways in use.

4.6.2 Terminal Manuevering Area

The area inside the feeder fix is referred to as the terminal maneuvering area. The nominal route in the vicinity of the arrival runway can be located on the working maps as a final approach segment which is approximately 10 nm long. To enter the final approach, 5 nm left and right base leg flight paths are used. In metroplex areas it may be necessary to eliminate one of the base legs due to the limited availability of airspace.

Either of two design techniques can be used in connecting the feeder fix to the base leg. Both options are shown in Figures 15 and 16. The first option, shown in Figure 15, has the arrival traffic proceeding toward the center of the airport and then turning to a downwind leg at a distance of about 7 - 8 nm from the airport. The second option, shown in Figure 16, has the arrivals make a modified downwind by proceeding directly from the feeder fix to the base leg. The procedure is slightly shorter for the arrivals than is the conventional downwind approach. However, this approach imposes more constraints on departure traffic than does the conventional approach. Either design option can produce satisfactory terminal maneuvering area route structures.

4.6.3 Departure Routes

The departure traffic is assumed to climb out on the runway heading for a distance of 2 to 5 nm and then turn toward the desired departure waypoint on the terminal boundary. On some departure routes it may be necessary to modify the route so that some airspace is available for the aircraft to climb to an altitude so that no altitude conflicts with arrival traffic occur.

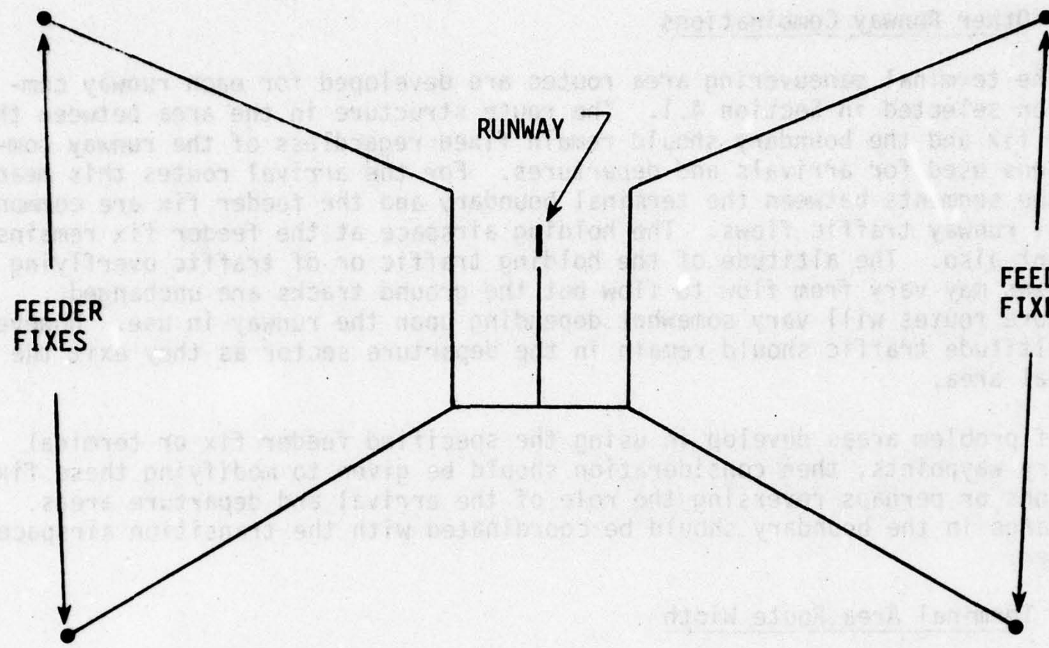


FIGURE 15 Conventional Downwind

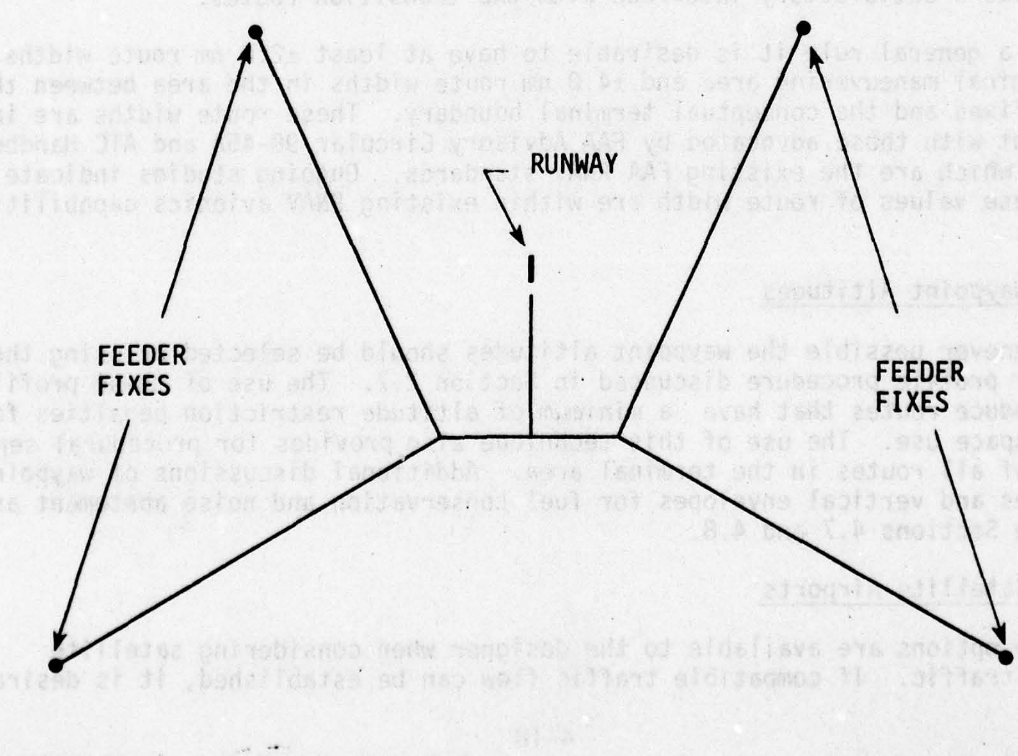


FIGURE 16 Modified Downwind

Additional altitude considerations are discussed in Section 4.6.6. In general the technique used to develop departure routes is to provide the shortest path available to the terminal boundary with adjustments made for maintaining procedural separation from arrivals.

4.6.4 Other Runway Combinations

The terminal maneuvering area routes are developed for each runway combination selected in Section 4.1. The route structure in the area between the feeder fix and the boundary should remain fixed regardless of the runway combinations used for arrivals and departures. For the arrival routes this means that the segments between the terminal boundary and the feeder fix are common for all runway traffic flows. The holding airspace at the feeder fix remains constant also. The altitude of the holding traffic or of traffic overflying the fixes may vary from flow to flow but the ground tracks are unchanged. Departure routes will vary somewhat depending upon the runway in use. However, high altitude traffic should remain in the departure sector as they exit the terminal area.

If problem areas develop in using the specified feeder fix or terminal boundary waypoints, then consideration should be given to modifying these fix locations or perhaps reversing the role of the arrival and departure areas. Any change in the boundary should be coordinated with the transition airspace designer.

4.6.5 Terminal Area Route Width

In the Reference 1 study it was found that ±2.0 nm route widths were adequate in the terminal areas that were considered in that program. In addition the routes were spaced at least ±4.0 nm apart at the terminal boundary in order to provide a satisfactory interface with the transition routes.

As a general rule it is desirable to have at least ±2.0 nm route widths in the terminal maneuvering area and ±4.0 nm route widths in the area between the feeder fixes and the conceptual terminal boundary. These route widths are in agreement with those advocated by FAA Advisory Circular 90-45A and ATC Handbook 7110.18 which are the existing FAA RNAV standards. Ongoing studies indicate that these values of route width are within existing RNAV avionics capabilities as well.

4.6.6 Waypoint Altitudes

Whenever possible the waypoint altitudes should be selected by using the vertical profile procedure discussed in Section 2.7. The use of these profiles will produce routes that have a minimum of altitude restriction penalties for the airspace use. The use of this technique also provides for procedural separation of all routes in the terminal area. Additional discussions of waypoint altitudes and vertical envelopes for fuel conservation and noise abatement are found in Sections 4.7 and 4.8.

4.6.7 Satellite Airports

Two options are available to the designer when considering satellite airport traffic. If compatible traffic flow can be established, it is desirable

to incorporate the use of the primary fixes and boundary waypoints into the satellite routes. Altitude separation may or may not be required depending upon the level of satellite traffic, controller jurisdiction requirements, and the relative location of the primary and satellite airports.

The second option that may be used by the designer is to completely isolate and separate the traffic flow to the satellite airport. This procedure is often necessary when the satellite airport develops a significant fraction of the terminal area traffic. This design option often results in overlapping airspace requirements and restriction of airspace for both the primary and secondary airport route structure. The first option should be used where possible as the user benefits are generally higher in this arrangement.

4.6.8 Metroplex Terminal Area Routes

The design of metroplex area route structures, such as in the New York area where three primary airports are found, generally requires a considerable amount of trial and error design technique. The procedures used for the simpler terminal areas can be used as a starting point, but the procedure generally produces poor results for both the user and controller if carried too far without using some flexibility and judgment. The development of separate, parallel arrival and departure routes can sometimes be used to advantage to minimize the number of crossing routes. Considerable attention must be given to the altitude profiles in the metroplex areas so that excessive user penalties do not appear.

The location and use of feeder fixes in a metroplex area requires the use of some judgment on the part of the airspace designer. Often it is possible to utilize the same feeder fix location for two or more airports within the metroplex. The ability and desirability of doing this depends upon the location, of the airports, controller jurisdiction requirements, and the traffic demand of each of the airports for aircraft using that specified feeder fix. Often separate altitudes may be used for traffic going to each of the airports that utilize the fix. Finally, if traffic demand at the fix becomes too great for satisfactory ATC operation or for efficient user operations, then it is necessary to separate traffic to the different airports by establishing additional feeder fixes and separate route structures to the airports.

4.6.9 Example RNAV Terminal Route Structures

An RNAV route structure for Philadelphia is shown in Figure 17. This design procedure made use of the modified downwind approach procedure as shown on routes 206 and 209. Note that in this route structure, departure traffic on routes 301 and 310 top the arrivals on the modified downwind leg. An RNAV terminal route design for Miami is shown in Figure 18. In this design the conventional downwind approach has been used in developing routes 201, 202, 203 and 204. The departure traffic in this configuration tunnels under the arrivals and then climbs without restriction after the arrival route is passed. Either traffic flow can be used in most single airport terminal areas. The most appropriate design depends upon the terminal area traffic patterns and other factors such as satellite traffic, adjoining terminal areas, etc.

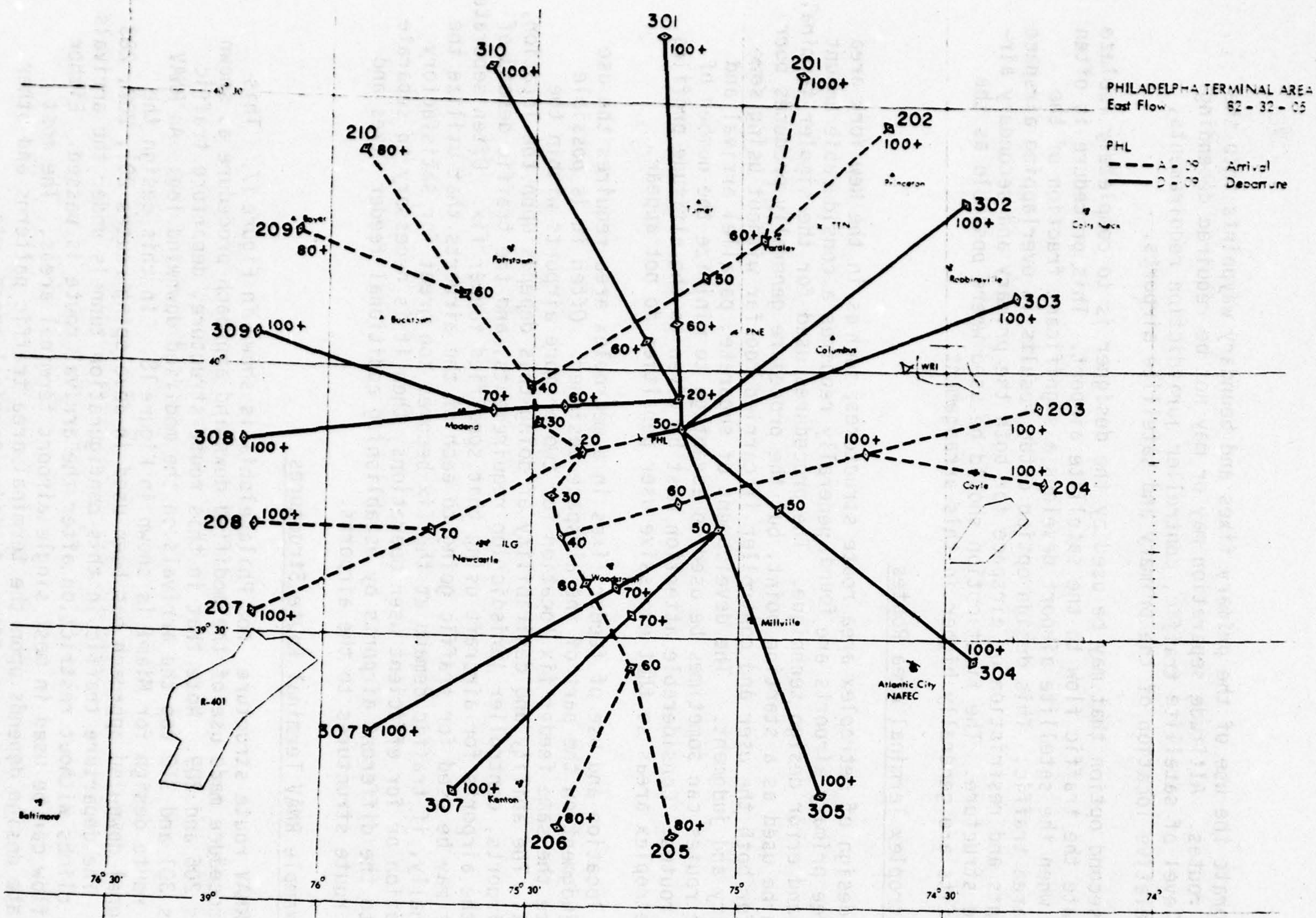


Figure 17 Philadelphia Terminal Area - RNAV Route Structure - East Flow

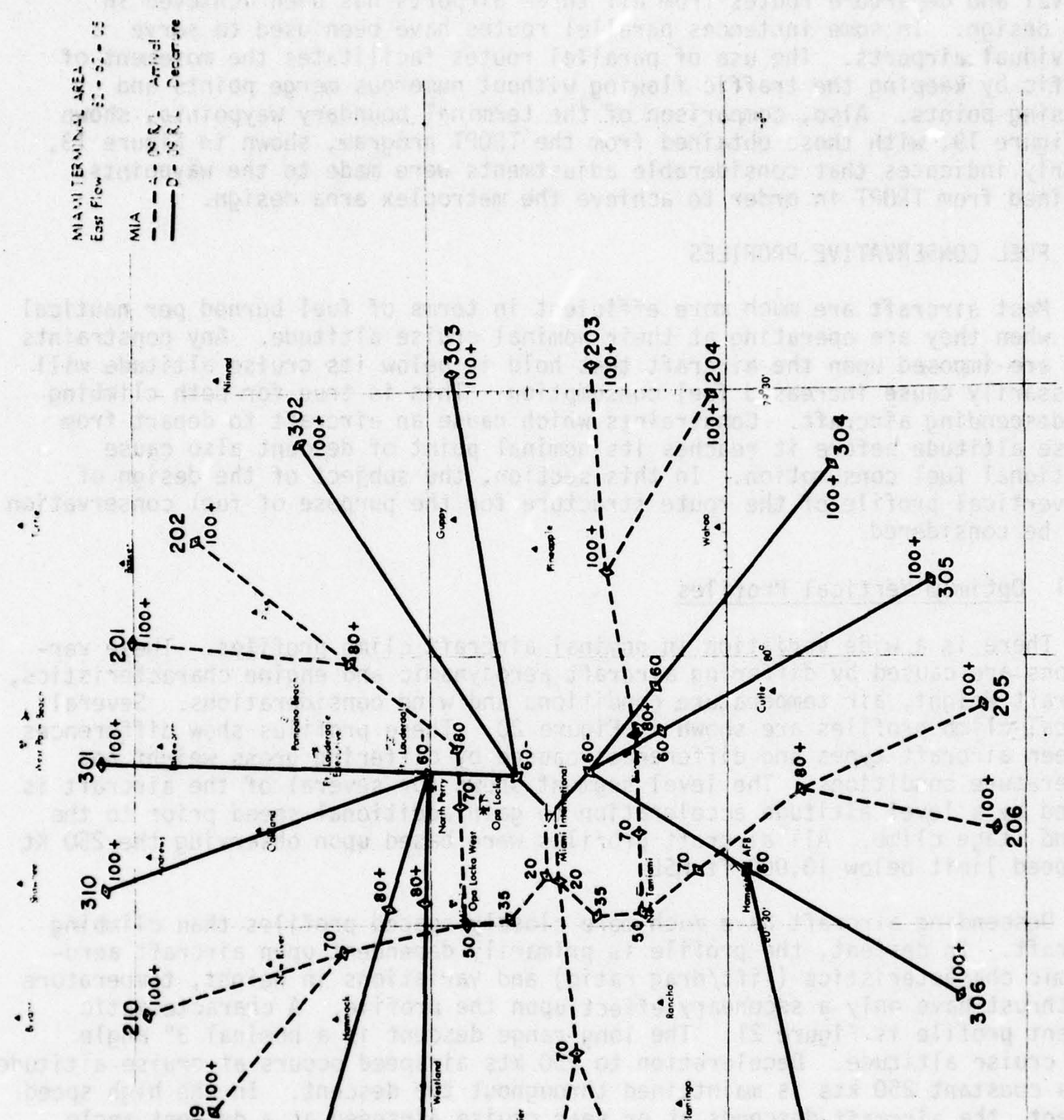


Figure 18 Miami Terminal Area - RNAV Route Structure - East Flow

The complex New York terminal area RNAV route structure developed during the Reference 1 study is shown in Figure 19. Procedural separation of all arrival and departure routes from all three airports has been achieved in this design. In some instances parallel routes have been used to serve individual airports. The use of parallel routes facilitates the movement of traffic by keeping the traffic flowing without numerous merge points and crossing points. Also, comparison of the terminal boundary waypoints, shown in Figure 19, with those obtained from the TROPT program, shown in Figure 13, clearly indicates that considerable adjustments were made to the waypoints obtained from TROPT in order to achieve the metroplex area design.

4.7 FUEL CONSERVATIVE PROFILES

Most aircraft are much more efficient in terms of fuel burned per nautical mile when they are operating at their nominal cruise altitude. Any constraints that are imposed upon the aircraft that hold it below its cruise altitude will necessarily cause increased fuel consumption. This is true for both climbing and descending aircraft. Constraints which cause an aircraft to depart from cruise altitude before it reaches its nominal point of descent also cause additional fuel consumption. In this section, the subject of the design of the vertical profile of the route structure for the purpose of fuel conservation will be considered.

4.7.1 Optimum Vertical Profiles

There is a wide variation in nominal aircraft climb profiles. These variations are caused by differing aircraft aerodynamic and engine characteristics, aircraft weight, air temperature conditions and wind considerations. Several typical climb profiles are shown in Figure 20. These profiles show differences between aircraft types and differences caused by differing gross weight and temperature conditions. The level segment shown for several of the aircraft is caused by a level altitude acceleration to gain additional speed prior to the second stage climb. All aircraft profiles were based upon observing the 250 Kt airspeed limit below 10,000 ft MSL.

Descending aircraft have much more closely spaced profiles than climbing aircraft. In descent, the profile is primarily dependent upon aircraft aerodynamic characteristics (lift/drag ratio) and variations in weight, temperature and thrust have only a secondary effect upon the profile. A characteristic descent profile is Figure 21. The long range descent is a nominal 3° angle from cruise altitude. Deceleration to 250 kts airspeed occurs at cruise altitude and a constant 250 kts is maintained throughout the descent. In the high speed descent, the aircraft descends at or near cruise airspeed at a descent angle of approximately 4°. At 10,000 ft MLS the aircraft is leveled and decelerated to 250 kts prior to penetrating the 10,000 ft altitude. Below 10,000 ft there is no difference in the two descent profiles.

When designing the altitude crossing values for the RNAV routes, it is important to consider the vertical profiles shown in Figures 20 and 21. If altitudes may be kept within the ranges shown on these figures, then fuel efficient climb and descent procedures can be achieved by most aircraft. When crossing traffic or other operational problems cause the aircraft to be kept

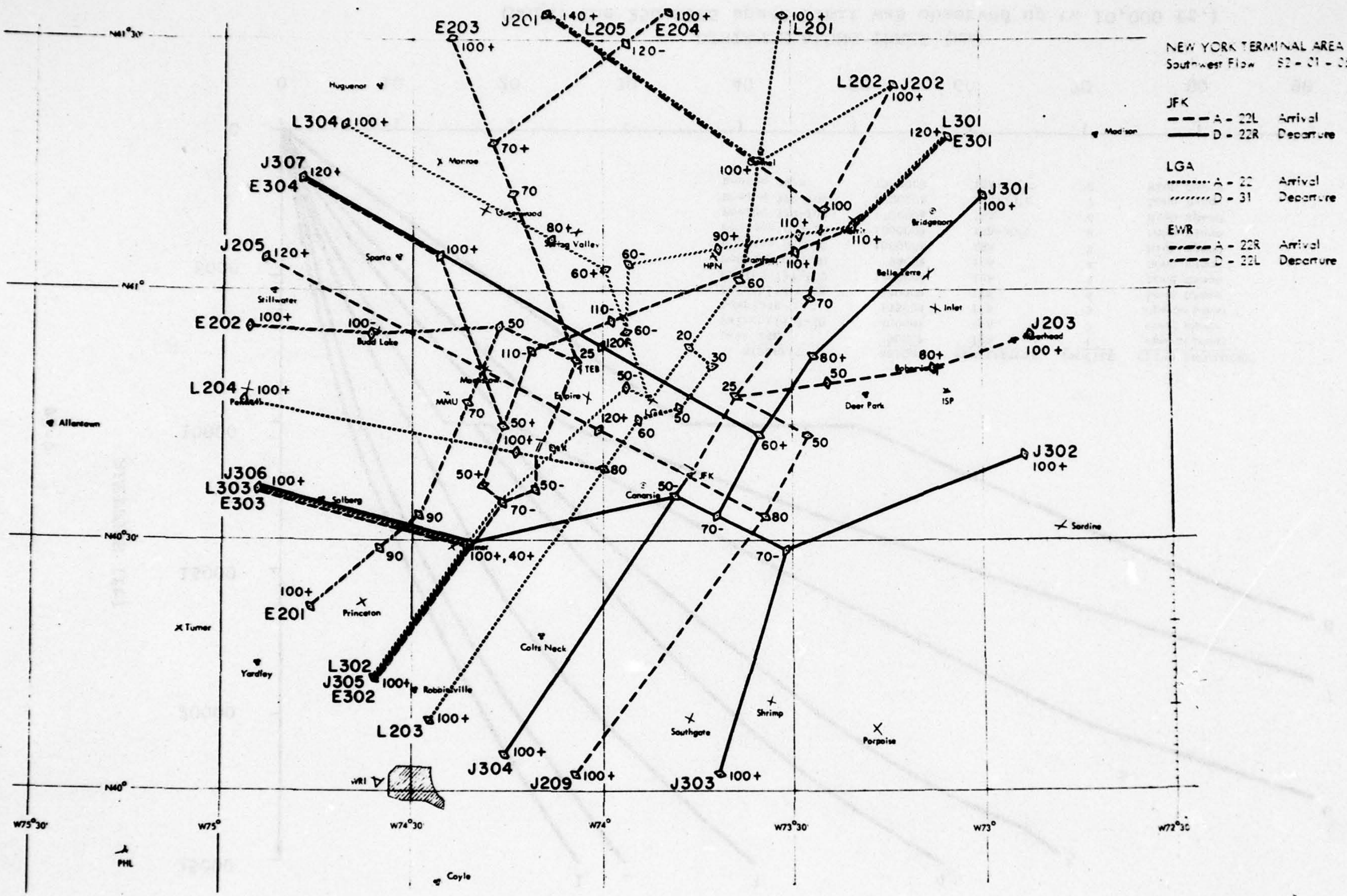


Figure 19 New York Terminal Area - RNAV Route Structure - Southwest Flow

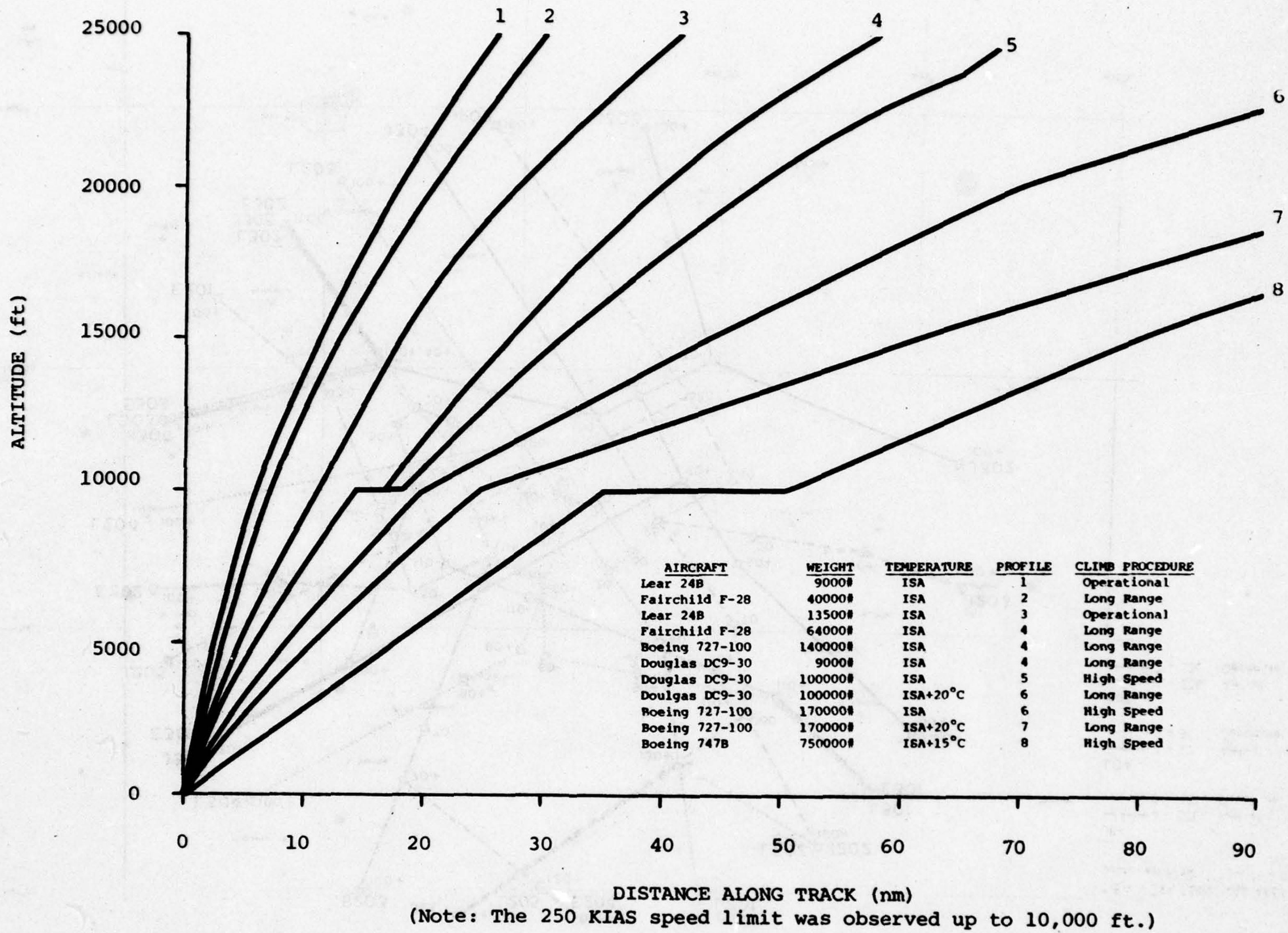


FIGURE 20 Typical Aircraft Climb Profiles

AIRCRAFT	WEIGHT	TEMPERATURE	PROFILE	CLIMB PROCEDURE
Lear 24B	9000#	ISA	1	Operational
Fairchild F-28	40000#	ISA	2	Long Range
Lear 24B	13500#	ISA	3	Operational
Fairchild F-28	64000#	ISA	4	Long Range
Boeing 727-100	140000#	ISA	4	Long Range
Douglas DC9-30	9000#	ISA	4	Long Range
Douglas DC9-30	100000#	ISA	5	High Speed
Doulgas DC9-30	100000#	ISA+20°C	6	Long Range
Roeing 727-100	170000#	ISA	6	High Speed
Boeing 727-100	170000#	ISA+20°C	7	Long Range
Boeing 747B	750000#	ISA+15°C	8	High Speed

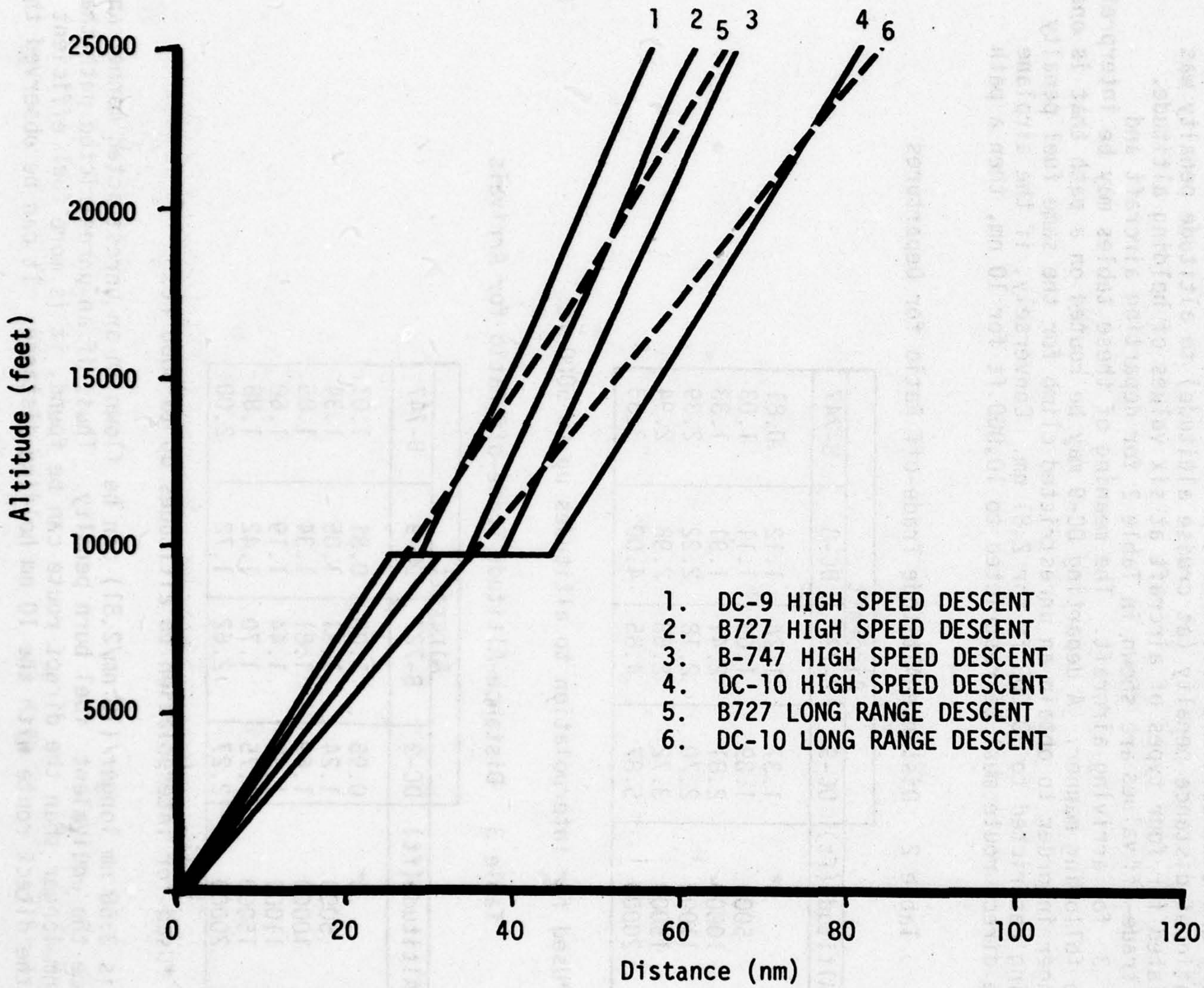


Figure 21 Typical Aircraft Descent Profiles

below these altitude values, then increased fuel consumption will occur. If the waypoint altitudes call for heights above (below) those shown on the figure for departure (arrivals), then these altitudes may be beyond the performance capability of the aircraft.

4.7.2 Distance-Altitude Trade-offs

At times during the RNAV terminal design process, it is necessary to choose between a longer, but unrestricted, path to (or from) the terminal boundary and a direct, but restricted, path. In order to make this trade-off, the ratio of distance penalty (at cruise altitude) to altitude penalty was calculated for four types of aircraft at six values of holding altitude. These trade-off values are shown in Table 2 for departing aircraft and Table 3 for arriving aircraft. The meaning of these tables may be interpreted in the following manner. A departing DC-9 may be routed on a path that is one nm longer in order to obtain an unrestricted climb for the same fuel penalty as being restricted to 10,000 ft for 2.81 nm. Conversely, if the airplane on the direct route must be restricted to 10,000 ft for 10 nm, then a path

Table 2 Distance-Altitude Trade-off Ratio for Departures

	Aircraft			
Altitude(ft)	DC-9	B-727	DC-8	B-747
0*	1.37	1.24	1.12	0.81
5000	1.89	1.68	1.11	1.03
10000	2.81	2.41	1.91	1.33
11000	2.70	2.18	2.22	2.39
15000	3.72	2.68	2.98	2.94
20000	5.87	4.85	4.00	3.33

*Used for interpolation to altitudes up to 5000 ft.

Table 3 Distance-Altitude Trade-off Ratio for Arrivals

	Aircraft			
Altitude(ft)	DC-9	B-727	DC-9	B-747
0*	0.95	1.00	0.81	1.01
5000	1.24	1.31	1.05	1.34
10000	1.69	1.81	1.34	1.85
11000	1.38	1.44	1.19	1.60
15000	1.75	1.70	1.42	1.88
20000	2.27	2.62	1.72	2.00

*Used for interpolation to altitudes up to 5000 ft.

that is 3.56 nm longer (10 nm/2.81) can be flown in an unrestricted manner and produce the equivalent fuel burn penalty. Thus, if an unrestricted path that is 3 nm longer than the direct route can be found, it is more fuel efficient than the direct route with the 10 nm holding distance. It can be observed that

as the altitude increases, it becomes increasingly efficient to restrict the aircraft profile rather than to add additional flight miles in order to obtain an unrestricted climb or descent.

4.7.3 Use of VNAV Procedures

Many RNAV avionics contain the capability to compute and display VNAV (or 3D-RNAV) information to the pilot. This system can be used to improve fuel efficiency in climb and descent if the route is designed to accommodate VNAV procedures.

For arriving aircraft, the VNAV system can be used to identify the point of descent initiation so that the waypoint may be crossed at the desired altitude. This procedure results in more closely controlled descents than does the conventional descent which utilizes the altimeter and a standard descent rate to achieve the appropriate waypoint crossing altitude. An example of the advantages of the delayed descent procedure is shown in Figure 22. The VNAV equipped aircraft knows at which point it is necessary to begin descent in order to cross the waypoint at the proper altitude. The conventional aircraft must descend prior to the VNAV descent point because it lacks the information necessary to precisely determine the desired descent point and thus must descend early so as to be assured of crossing the waypoint at the proper altitude. The route designer should provide sufficient airspace in the vertical dimension to permit the use of both the VNAV and the conventional descent procedure.

4.7.4. High Performance Departure Routes

For departing aircraft the use of high performance departure routes can be used in some areas to shorten the flight path within the terminal area. A high performance departure route is a route that is developed for the use of fast climbing aircraft in order that they may have available within the terminal area a shorter route, or a route with less altitude restrictions, or both. The high performance route is usually characterized by some minimum achievable altitude within a specified distance. An example of how a high performance route could be used effectively is shown in Figure 23. Aircraft departing the terminal area on the nominal route climb from point A at 6000 ft to point C, at or above 13,000 ft and then turn right and continue to climb to the terminal boundary, point D, which they cross at or above 16,000 ft. The 13,000 ft or above altitude is required in order to top the crossing route which may have traffic at altitudes ranging from 6000-12,000 ft. If the departing aircraft is a fast climber, and if it can achieve the altitude of 13,000 ft at or before point B, then the high performance departure route may be used.

An example of the use of a high performance route that overlies a RNAV departure route is shown in Figure 24. In this example RNAV departures on routes 304 and 305 are restricted to 5,000 ft until they are clear of arrivals on routes 203 and 204. Some high performance aircraft can top these arrivals if they are able to achieve an altitude of 9000 ft or above prior to crossing the arrival route. Thus provisions have been made for this departure by designating two altitude values, 5000 and 9000 ft and above, for the restriction point on routes 304 and 305 that are immediately north of the arrival route.

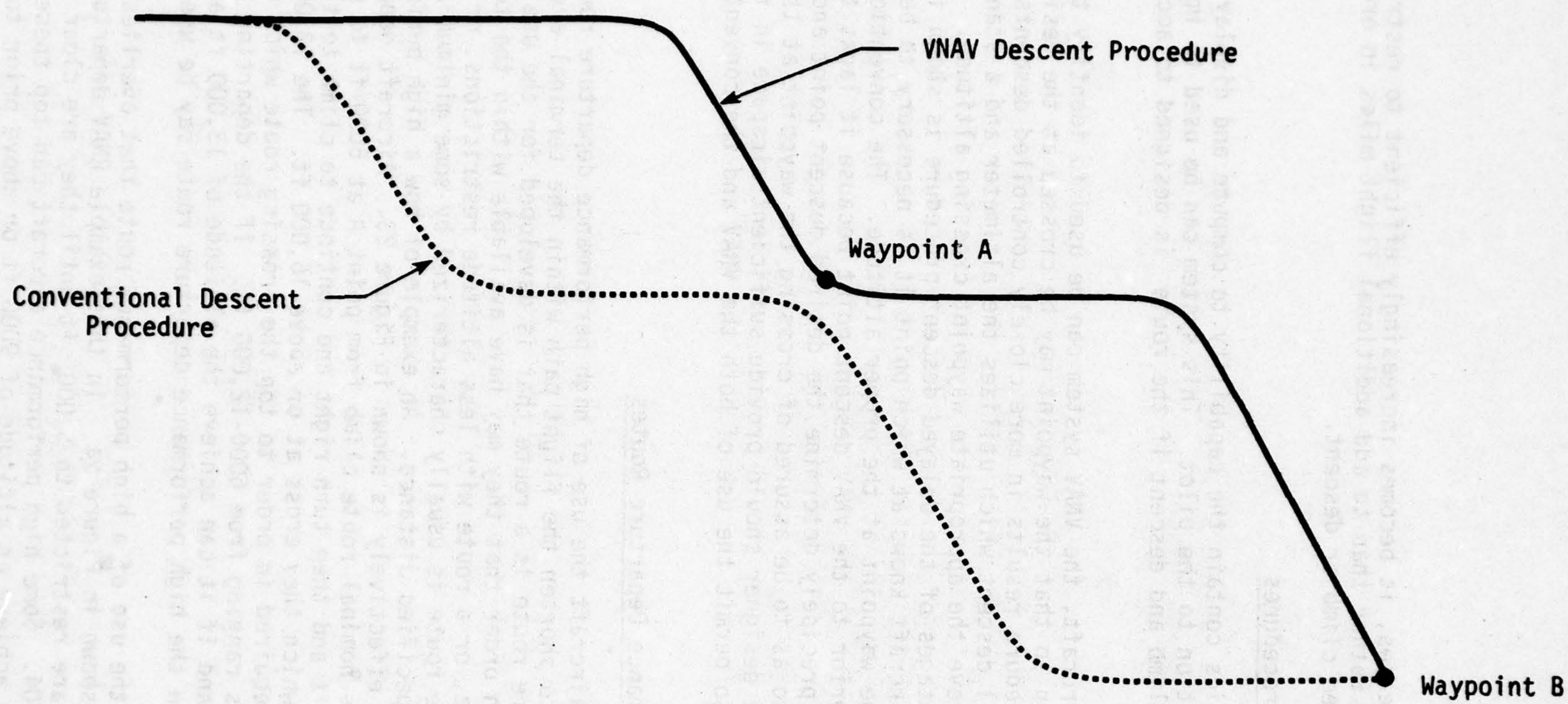


Figure 22 Comparison of VNAV and Conventional Descent Procedures

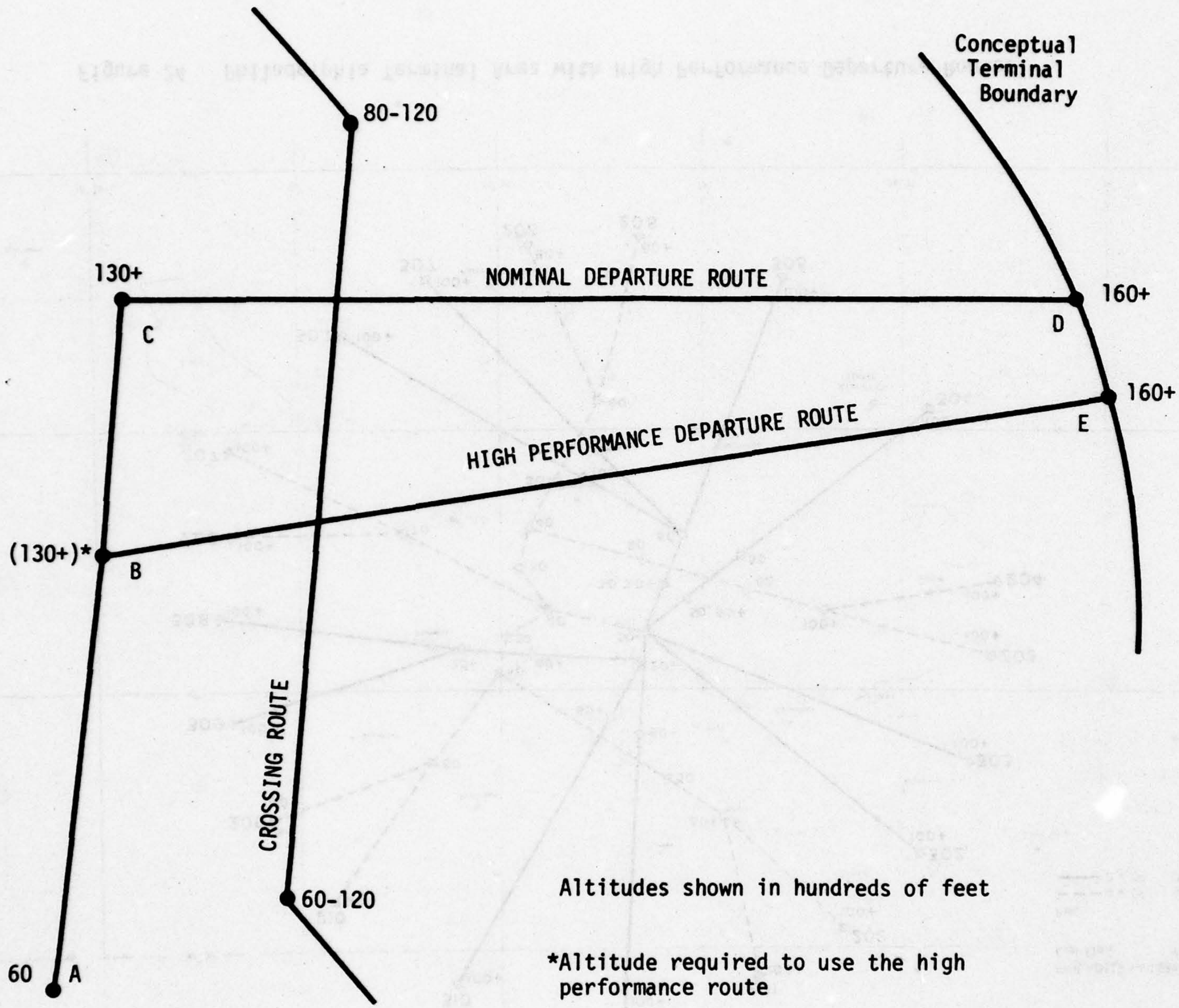


Figure 23 High Performance Departure Route Geometry

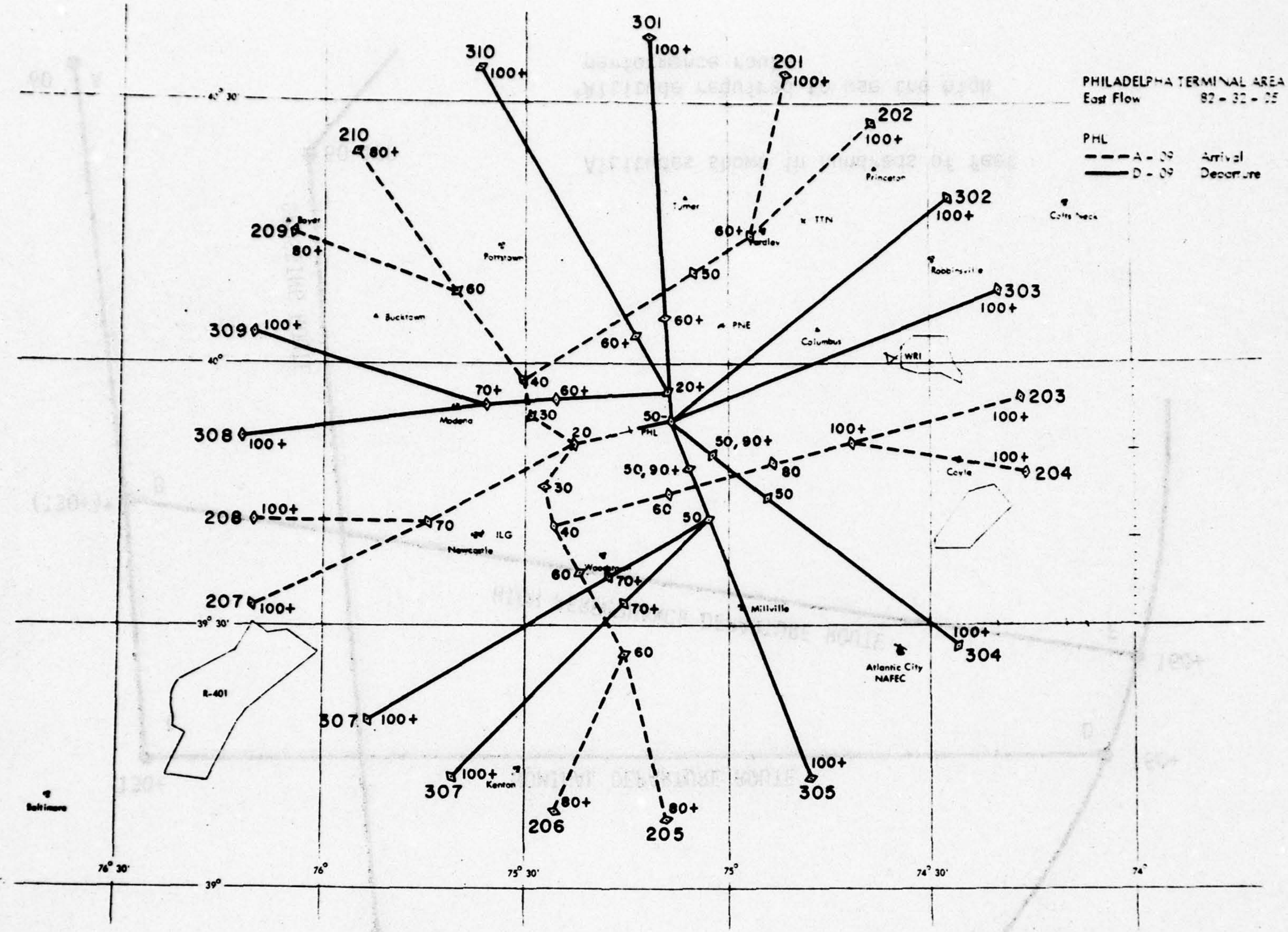


Figure 24 Philadelphia Terminal Area with High Performance Departure Routes

Arrivals are restricted to 8000 ft just prior to the intersection of joint route 204-205 and route 304 so that vertical separation is assured at the route intersection.

In developing the high performance departure routes, it is important to have knowledge of the distance versus altitude characteristics of the route and the aircraft so that realistic altitude assignments can be made. This can be achieved by using the profile charts and procedures that are discussed in Section 2.7.

4.8 NOISE CONSTRAINTS

In the airspace near the airport, where operations will be occurring at altitudes less than 5000 ft above ground level, it may often be necessary to consider noise abatement procedures when developing RNAV route structures. The use of RNAV can facilitate noise abatement procedures by permitting routes to be developed over less noise sensitive areas and by providing more positive vertical path control than can be achieved through radar vectors.

4.8.1 RNAV Route Location

In many terminal areas there are noise abatement approach and departure procedures that are used in visual meterological conditions which can not be used in instrument conditions because the approach and landing aids are not capable of supporting the procedures. With area navigation however, it is often possible to develop RNAV routes that nearly duplicate the visual procedure. An example of how this can be achieved is shown in Figure 25. The Deleware River visual approach to Philadelphia International Airport uses the 063° radial of the Newcastle VOR. Upon reaching the 10 nm DME point the approach can be continued only if the ceiling exceeds 4500 ft and the visibility is 3 miles or greater. Assuming that navaid coverage from Woodstown VOR is available, an RNAV approach could be developed along the same general flight path as the visual approach which would terminate at a missed approach point near the runway threshold and have a minimum descent altitude on the order of 600-700 ft.

Similar procedures can be used for departing aircraft. RNAV SID routes can be used to direct the traffic over less noise sensitive areas such as rivers, lakes, swamps, etc. These factors should be considered in the design of RNAV routes in the vicinity of the airports.

4.8.2 VNAV Delayed Descent

The VNAV delayed descent procedure that was discussed in Section 4.7.3 in terms of fuel conservation, can be effectively used to provide some noise reduction at ground level. The intensity of aircraft noise varies inversely with the altitude of the aircraft. The VNAV delayed descent procedure keeps the aircraft at its highest practical altitude during the entire descent.

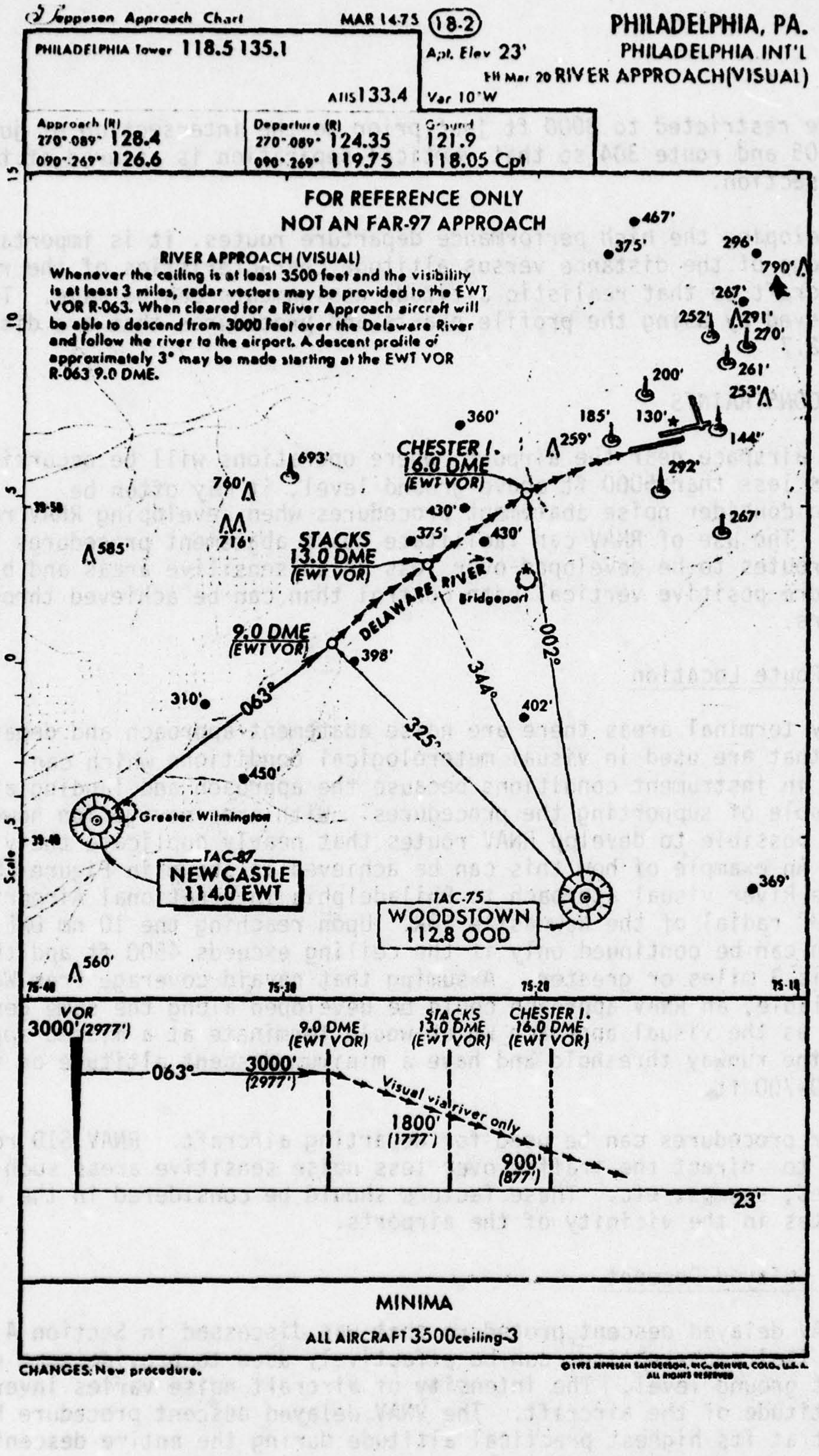


Figure 25 Delaware River Visual Approach to Philadelphia International Airport

Consequently, the noise intensity in the vicinity of the aircraft ground track should be less for equivalent types of VNAV equipped aircraft. The RNAV (but non-VNAV) equipped aircraft can maintain a vertical descent profile that is nearly as beneficial from a noise standpoint as the VNAV aircraft. This can be achieved by using the along track distance output of the RNAV and typical descent rates for the aircraft. Both RNAV and VNAV descent procedures are superior to radar vector procedures for maintaining noise abatement descent profiles.

4.9 ADDITIONAL DESIGN CONSTRAINTS

While the RNAV routes are being developed it is often necessary to consider specific terminal area problems. These problems could include the following:

- restricted airspace
- noise sensitive areas
- noise abatement procedures
- area lacking in adequate coverage
  - navigation
  - radar
  - communication
- interface with an adjacent terminal area
- maneuvering airspace requirements
- transition/enroute design requirements

The consideration of these problem areas will usually necessitate some modification to the RNAV route structure. If these constraints are considered as the design is being developed, then the changes may be made without too much difficulty. During the course of the Reference 1 study, a number of these constraints were incorporated into the RNAV terminal designs. In general, their incorporation in the route design produced little or no impact upon the basic terminal route structure. If a major design change becomes necessary due to one of these constraints, then consideration should be given to reversing the function of the arrival-departure sectors or to modifying the arrival-departure airspace areas. This would necessitate an additional transition area coordination task to determine the impact upon adjoining airspace areas.

4.10 EVALUATION OF CANDIDATE RNAV DESIGNS

Once the RNAV route structures are completed, then it is appropriate to begin the user impact evaluation of the candidate designs. This is accomplished in much the same manner as the VOR/radar vector airspace evaluation that is described in Sections 4.2 and 4.3. The waypoints and route structures are recorded in data files and processed using the ASMBL and TMALST programs. Once an RNAV route structure file has been prepared for each of the traffic flows and for each major satellite airport, then the TEVALP program may be used to compute the route length, misalignment distance and altitude restriction penalties associated with the use of the RNAV routes.

The output of the TEVALP program should be scrutinized carefully for unobtainable aircraft altitudes and excessive aircraft time or fuel penalties on all route segments. If either of these conditions are observed, then the RNAV route design ought to be re-examined for possible changes to improve its user benefit parameters.

4.11 COMPARISON OF TERMINAL ROUTE STRUCTURES

Direct comparison of route structures in terms of user time and fuel benefits can be made by using the TACOMP program. The input data for TACOMP are two outputs of TEVALP. One TEVALP output is an evaluation of the conventional VOR/radar vector route structure. The second TEVALP output is the evaluation of the RNAV route structure for the same runway combinations and aircraft types that were used in the TEVALP output for the conventional routes.

An example TACOMP output is shown in Figure 26 for the west flow at Philadelphia. It can be observed that time and fuel benefits (or penalties) are given for each aircraft type. The benefits are computed for arrivals and departures separately and then averaged to produce an average benefit value for the specific traffic flow.

The average RNAV benefit (or penalty) for the airport may be computed by summing the individual benefits for each traffic flow weighted by the utilization of the traffic flow. This benefit can be represented by the following expression:

$$B_A = \sum_{i=1}^{N} U_i \, B_i$$

where

B_A = average airport benefit
B_i = benefit for the i th traffic flow
U_i = percent utilization of the i th traffic flow
N = number of traffic flows for which designs were developed

The total average benefit for the terminal area is computed by averaging the benefit for each airport in the terminal area weighted by the traffic using that airport. This benefit may be expressed by the following equation

$$B_T = \sum_{j=1}^{M} T_j \, B_j$$

where

B_T = total terminal area benefit
T_j = percent of terminal traffic for the j th airport
B_j = benefit for the j th airport
M = number of airports in the terminal area for which designs were developed

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     COMPARISON OF 72-32-05   77/12/21. AND 52-32-07   77/12/20.

     ARRIVAL DATA

DISTANCE BENEFIT  51.53- 52.06= -.53

MISALIGMENT DISTANCE BENEFIT  1.19- 1.28= -.09

  DC-9 BENEFIT         .104 MIN        11.8 LBS
  B727 BENEFIT         .127 MIN        17.1 LBS
  DC-8 BENEFIT         .143 MIN        37.4 LBS
  B747 BENEFIT         .147 MIN        41.7 LBS

     DEPARTURE DATA

DISTANCE BENEFIT  55.45- 54.22= 1.23

MISALIGMENT DISTANCE BENEFIT  .77-  .48=  .29

  DC-9 BENEFIT         .353 MIN        34.6 LBS
  B727 BENEFIT         .351 MIN        48.9 LBS
  DC-8 BENEFIT         .353 MIN        92.7 LBS
  B747 BENEFIT         .343 MIN       152.8 LBS

AVERAGE BENEFITS

  DC-9 BENEFIT         .229 MIN        23.2 LBS
  B727 BENEFIT         .239 MIN        33.0 LBS
  DC-8 BENEFIT         .251 MIN        65.0 LBS
  B747 BENEFIT         .245 MIN        98.8 LBS
END OF INFORMATION ENCOUNTERED.
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Figure 26 TAPE3 Output File from TACOMP

The above benefit computations are determined for each aircraft type that is used within the terminal area. The benefit average for all aircraft may be developed in a manner similar to the airport and terminal area benefits. The result, averaged by aircraft type, produces the average per operation benefit for any aircraft that operates in the terminal area. This figure of merit for the RNAV terminal area design is very useful for extrapolating benefits to annual savings and other economic factors.

If some of the terminal benefit factors are negative or smaller than desired, the cause or causes of this condition can be examined by analyzing the results of the TEVALP and TACOMP programs. These examinations may lead to areas within the RNAV design which could be improved from the user's standpoint. Changes in the RNAV design at this point necessitate a reevaluation of the RNAV route structures using TEVALP and TACOMP on the revised route structures.

4.12 EXTENSION OF DESIGN TO OTHER TRAFFIC FLOWS

The RNAV route design process has been used to evaluate major terminal traffic flows up to this point. As one of the final design tasks, route structures in the terminal maneuvering area should be developed for lesser used traffic flows and runway combinations. Adverse user benefits for these traffic flows will not generally affect overall benefits. However, any conditions that will result in unsatisfactory or undesirable traffic control procedures may necessitate changes in the terminal design.

4.13 USE OF THE RNAV DESIGN BY NON-RNAV AIRCRAFT

The RNAV terminal design represents a design goal which may only be achieved in its entirety in an all-RNAV environment. However, in many terminal areas it may be possible to incorporate many of the RNAV terminal area routes into the existing VOR route structure. One design procedure by which this may be accomplished is the selection of the arrival and departure sectors as described in Section 4.4. It was noted in this section that in selecting the arrival and departure sectors, there is an ambiguity associated with this procedure. If the ambiguity is resolved by considering the existing traffic patterns, it is often the case that some existing arrival-departure areas will correspond quite closely with desired RNAV arrival-departure areas.

Another procedure which can be used to incorporate the RNAV design into existing terminal routes is to attempt to connect existing high and low altitude VOR routes to the desired feeder fix locations of the RNAV route structure. Also, departure routes can be connected to the VOR route structure rather than to the boundary waypoints. In the Reference 1 study, this procedure was used in the Miami and San Francisco terminal areas with some degree of success. The routes for these two terminal areas are shown in Figures 27 and 28. The routes numbered between 001 and 005 denote VOR arrival routes and routes 101-106 represent VOR departure routes in this basic RNAV route structure design. It may be necessary to move a feeder fix or an RNAV route in these mixed conventional and RNAV route structures in order to achieve procedural separation and sufficient maneuvering airspace. Ideally, a compatible route structure may be worked out for VOR and RNAV traffic so that user benefits and RNAV traffic control procedures can be used to their full advantage.

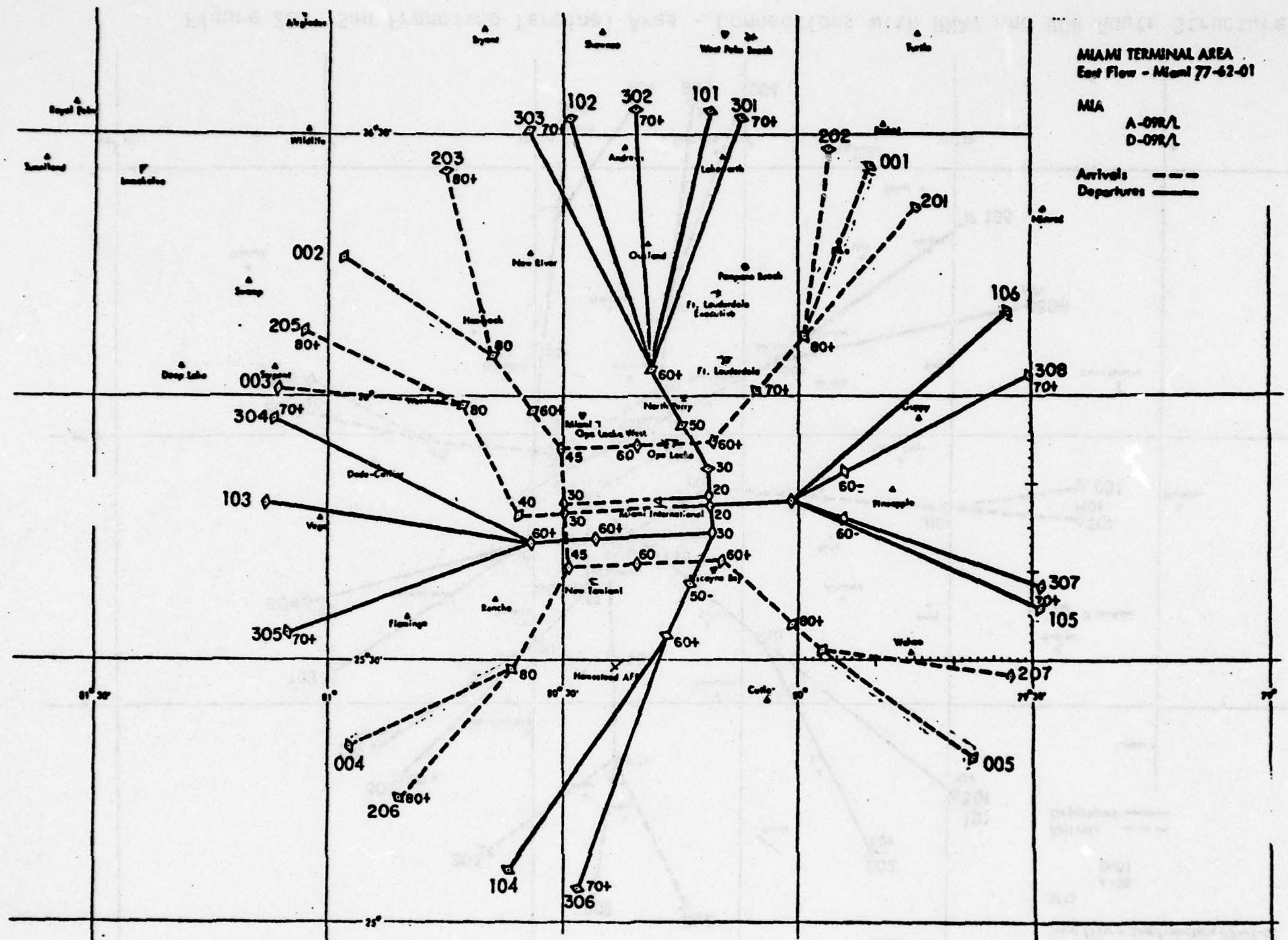


Figure 27 Miami Terminal Area - Connections with RNAV and VOR Route Structures

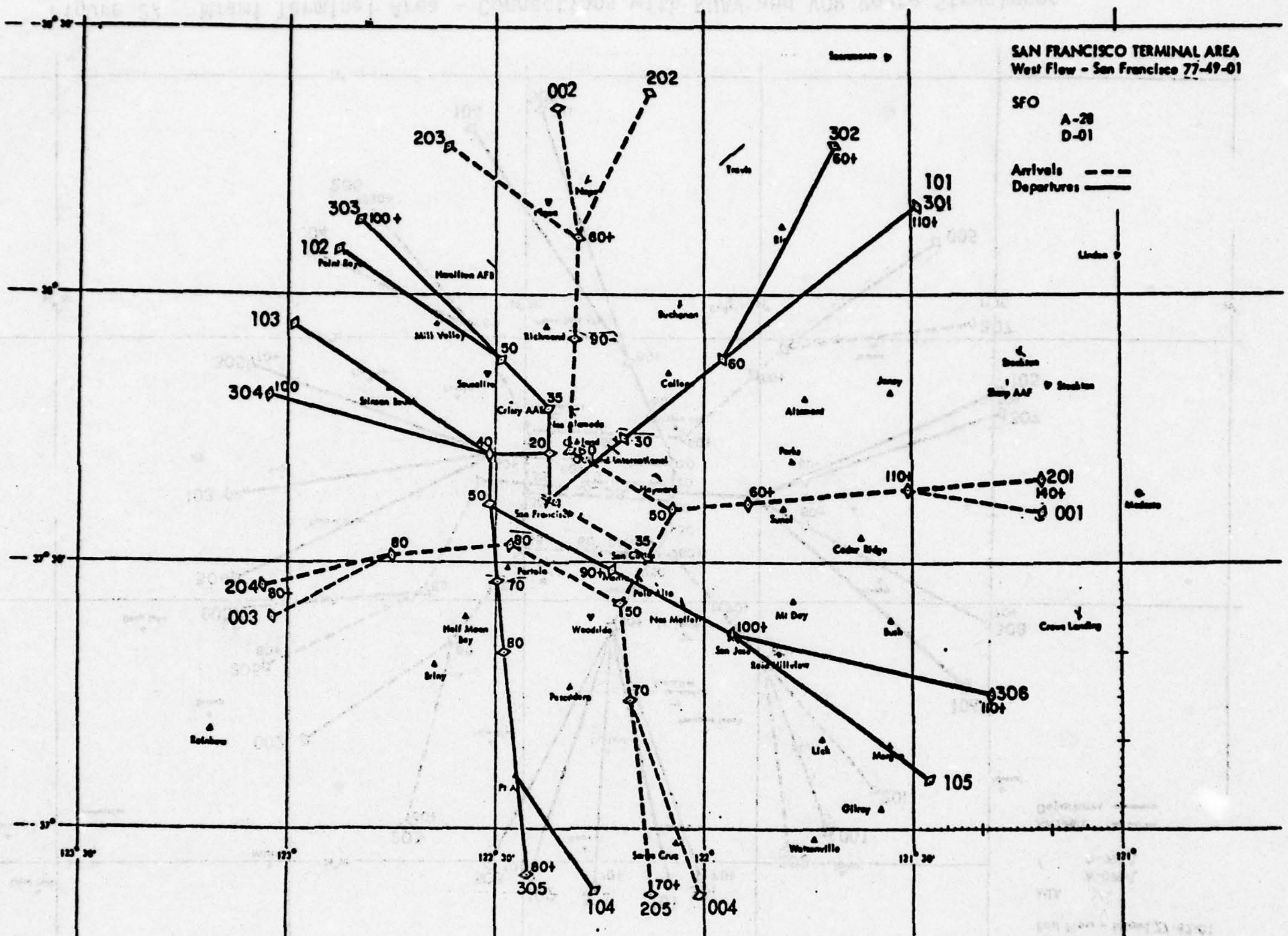


Figure 28   San Francisco Terminal Area - Connections with RNAV and VOR Route Structures

4.14 SUMMARY

The preceding paragraphs have described the RNAV terminal area design procedures that were developed in the Reference 1 study. The terminal designer, who may use some or all of these design techniques, may obtain further insight into these design procedures by reviewing the examples contained in this report and those in Reference 1. For an in-depth discussion of the algorithms and software associated with the data processing programs that are used in these design procedures, the designer is referred to Appendix A.

The design procedure calls for a combination of designer experience, insight and intuition coupled with the use of data processing programs for quantatitive development and evaluation. It is felt that this combination of man-machine interaction will produce RNAV route structures that are superior in operational capability for the controller, the pilot and the aircraft operator than route structures developed entirely by either man or machine alone. The iterative nature of the design process provides for design evaluation after every step of the route design procedure. This closed-loop type of design practice should produce RNAV terminal route structures which are of significant benefit to all segments of terminal area operations. Good judgement and periodic coordination with adjacent airspace planners should be used throughout the terminal area design process.

5.0 INTRODUCTION TO TRANSITION AREA ROUTE DESIGN

Sections 5-10 of this report are devoted to the design of transition area airspace. As was discussed in Section 1.1, the transition area is less structured than the terminal area and so the techniques that are used in this region are based more upon design guidelines rather than step-by-step design procedures. This section, Section 5, presents the basic definitions and ground rules that apply to the transition design process. Section 6 deals with the organization of the transition route structure development process. This section describes the tasks and decision points that occur in the development of RNAV routes in the transition area. Section 7 describes the data elements that are useful in developing effective route structures. Section 8 presents the transition route design concepts and considerations. In this section many topics are discussed such as the interface with the terminal area, the use of one-way and two-way routes, the use of charted versus non-charted routes (parallel offset routes, non-charted transition routes, etc) for arrivals and departures, the interaction with the low altitude routes structure and the interface with airways that cross terminal airspace. Section 9 contains applications of the transition design guidelines. Four specific areas are considered. The first, Miami Northeast, is an example of heavy traffic flow in a single direction from a coastal city. The second, Chicago, is typical of a midcontinent city in which heavy traffic arrives and departs in almost all directions. The third area considered is the California Corridor where heavy traffic flows between two coastal cities with very little overflight or crossing traffic. The final area considered is the New York area which has heavy traffic flows in several directions, heavy crossing traffic in the transition areas and a considerable number of adjacent terminal areas in the vicinity of the transition area. These four examples provide a broad view of many of the problems that are encountered in the design of transition area airspace. The final section, Section 10, contains a summary discussion of the transition area design guidelines.

5.1 TRANSITION AREA DEFINITIONS

The purpose of Sections 5-10 is to delineate guidelines for the design of area navigation (RNAV) route structures in the airspace between the terminal and high-altitude enroute areas of aircraft operations. This airspace is referred to herein as the "transition area" and, in general, includes the airspace used for climb and descent between the assigned enroute altitude (upper airspace) and the altitude at the arrival and departure waypoints on the terminal perimeter. With this definition it is apparent that no fixed dimensions of the transition area are implied. It will be shown, in fact, that the size and shape of each transition area will depend upon several factors which are peculiar to that particular area. Also, transition route design for the low-altitude structure is not addressed even though in some areas these routes may be common with route structure segments used for transition to or from the high-altitude structure.

For the most part, these guidelines were derived from the terminal and enroute structure studies described in References 1 and 2, respectively. Although much of the discussion in these reports relates to the transition area, separate treatment of the transition area route design is considered warranted for two reasons: (a) in these studies, the benefits of RNAV in

the enroute environment were demonstrated to be the greatest during the transition phase of operations and (b) such benefits can easily be dissipated if appropriate design principles are not followed.

5.2 GROUND RULES

Conclusion No. 11 of Reference 2 (p. 163) states: "Terminal and enroute structures should be developed together in a systems approach so that the design of one does not impact unfavorably on the design of the other. This is particularly true in complex areas, such as the Golden Triangle, or where terminal areas are relatively close". This may not be possible, however, due to resources or other factors. Therefore, if enroute and terminal structures are developed separately, it is important that the following ground rules be observed:

- A common set of a priori design principles should be established for the number and location of the departure and arrival waypoints on the terminal perimeter in order to minimize the interface problems when the structures are integrated into a common network. (See pp. 82-94 of Reference 2.)

- Terminal and enroute structures should be developed in an iterative, or "cut-and-try" fashion, such as that described in Reference 1 and 2, in order to permit evaluation and modification at intermediate steps in the development process.

- Close and continuous coordination should be maintained between the terminal and enroute route structure development activities and, in particular, at each step in the iterative development process.

- A methodology should be developed and applied to evaluate the route structures for system effectiveness and user benefits. In the enroute high-altitude RNAV study, fast-time simulation proved to be of substantial benefit for system evaluation.

5.3 GENERAL DISCUSSION

In reviewing the RNAV High-Altitude Network Study (Reference 2) the following are evident:

- The potential for traffic interaction in the upper airspace is about three times as great where one or both aircraft are changing altitudes as opposed to the situation where both aircraft are level.

- When the capabilities of RNAV are applied effectively, the potential for traffic interaction during transition to/from enroute altitude is substantially reduced. In particular, the potential for head-on conflicts is minimized through use of one-way routes or route segments during climb and descent. Also, overtake conflicts can be reduced by use of multiple routes.

- In developing an enroute RNAV structure, consideration should be given to the transition phase of operations at the beginning of, and throughout, the development process as opposed to the "add-on" or piecemeal approach. If this principle is not followed, subsequent provision for transition to/from enroute altitude can cause a serious domino effect on the route structure design.

- For complex areas, such as the northeastern part of the U.S., the initial route structure design work should take into account traffic which the structure will ultimately accommodate even though it is not intended to provide RNAV routes for all traffic at that particular phase of development. In the Reference 2 study, route structures were developed in steps where each step was designed to accommodate progressively increasing traffic over the previous step. At each phase, consideration was given to the level of traffic specified for that phase as opposed to looking ahead to the requirements of the next phase. As a result, it became increasingly more difficult to modify the structure to accommodate added traffic. This was especially true in the area between New York and Chicago and in that area the deficiencies in the final design would have required a complete redesign to correct. Such redesign was beyond the scope of that study, however.

In addition to the above, it is apparent from the route structure development work described in Reference 2 (pp. 35-81) that a large portion of the design effort was centered on the transition area. In particular, considerable attention was given to developing transition area designs which would reduce the number of conflicts that occurred during fast-time simulation of the RNAV structure. The design philosophies that evolved from this work are embodied in the guidelines for transition route structures presented herein. In general, it was found that several different approaches to transition area route design are necessary to effectively exploit the capabilities of RNAV due to the variation of factors that exist at different locations. Examples of these variations are reflected in the geographical areas discussed below. Route design concepts that were developed during the Reference 2 study for these areas will be presented in Section 9.

5.4 EXAMPLE GEOGRAPHICAL AREAS

- <u>New York West and Southwest</u> - At this high density, coastal terminal most of the high-altitude traffic (approximately 85 percent) is exchanged with airports whose great circle bearings lie within a narrow band of less than 45°. This imbalance in traffic distribution requires special treatment for the configuration of the arrival and departure waypoints on the terminal parimeter. Also, the distances from New York to those airports varies from less than 300 miles to more than 2,200 miles and considerable crossing traffic exists in the airspace west of New York. Due to these factors, transition route designs in this area require special tailoring and may not, therefore, have general application throughout the U.S.

- <u>Chicago</u> - Unlike New York, the traffic demand at Chicago is distributed around most of the terminal perimeter, with the heaviest loads in the east-west direction. Therefore, in spite of the extreme traffic densities at Chicago, transition route design principles at this area should have application at other terminals, such as Atlanta, Denver, etc.

- <u>Cleveland</u> - This area presents the problems in transition route design which are associated with a high-density terminal having heavy over traffic.

- <u>Miami Northeast</u> - In the area northeast of the Miami terminal there is a heavy traffic exchange with several distant airports lying on a near common great circle bearing. Airspace is not at a premium and there is little crossing traffic in the upper airspace. Areas of this type lend themselves to near optimum application of RNAV in the transition phase of aircraft operations.

- <u>Los Angeles Northeast and San Francisco East</u> - These areas are similar to the airspace northeast of Miami except that there is a somewhat wider spread in the traffic distribution and there is more crossing traffic. Adequate airspace is available, however, for effective route design similar to that at Miami.

- <u>California Corridor</u> - High-altitude traffic between the Los Angeles and San Francisco metroplex areas is generally concentrated between 24,000 to 27,000 feet. Due to the relatively short distance (less than 300 miles) this traffic is either climbing or descending for a major portion of the route. Traffic exchange between the terminal areas is extremely heavy; therefore, an enroute/transition structure of multiple, one-way routes is required to avoid an undesirable traffic interaction problem. Such design, in turn, impacts on the transition in the easterly direction as well as on the terminal route structure designs. Best results will therefore be achieved in areas of this type through an integrated approach to the terminal, transition, and enroute route structure developments.

- <u>Dallas-Houston; St. Louis-Kansas City</u> - These city pairs are typical of terminals located relatively close with light to moderate traffic exchange in the upper airspace. This situation is prevalent throughout the U.S. and therefore, a relatively small set of transition route design principles will have broad application nationwide.

- <u>Golden Triangle (ORD-BOS-DCA)</u> - Although problems in transition route design for terminals in this area are generally included in previous examples, it is important to note the interacting effect that exists between terminals. Changes to one design frequently create a domino effect on the enroute structure and on other transition structures. Trade-offs are required for overall system effectiveness which may result in less than optimum designs when viewed independently. As with the California Corridor, an integrated approach of terminal, transition, and enroute route structure development will render best results.

6.0 ROUTE STRUCTURE DEVELOPMENT PROCESS

During the RNAV high-altitude network study (Reference 2) a methodology was developed which provided a systematic approach for the design and evaluation of RNAV routes in the enroute airspace. The appendix attached to Reference 2 contains a detailed description of the computer programs and design procedures that evolved during that study. That discussion is quite lengthy, and it would serve little purpose to repeat it in this guideline document. However, since a similar approach will probably be required for any future work in this area, a brief description of the process is provided in the sections that follow. This methodology is equally applicable to both enroute and transition route design, whether developed separately, or together in an integrated approach.

6.1 PROCESS OVERVIEW

The flow diagram on Figure 29 depicts a functional overview of the route structure development process that evolved during the Reference 2 study. From this diagram a few major points are evident. First, it can be seen that the process is centered around a manual design effort. This resulted from the early recognition that route structure development is a highly judgmental process that can only be automated to a limited degree. Automation techniques were developed to relieve routine computations, provide visual graphics, and perform other functions as their requirements became known and definable. It also can be seen that route structure development is planned to proceed in steps, with each step representing a refinement over the structure of the preceding step in a "trial and error" or iterative manner. In addition, the process is evolutionary in nature, wherein a simple network structure containing a limited number of city pairs is used to start. As experience is gained, the transition network can be made more complex until the desired portion of the traffic has been considered.

6.2 TRAFFIC ANALYSIS

Route structure development should start with a good analysis of the traffic that is to be accommodated by the structure. However, without the appropriate tools and convenient sources of data, this can be a difficult task. In the high-altitude study, computer programs were developed to process the "Peak Day IFR" data tape which is prepared each fiscal year by the Office of Management Systems (AMS-200). These data contain flight plan information (except route of flight) for the IFR traffic that was operating during each air route traffic control center's busiest day of the year. Since the peak day at one center will not necessarily be the same day of the year as at other centers, this data base reflects a composite (or mosaic) of peak traffic conditions rather than a single day of operations over the conterminous United States. Nevertheless, the data are useful in deriving estimates of traffic exchange between city pairs. The data also provide other useful information such as distribution of traffic by altitude, time, speed, user, and aircraft type. The flight plans can also be sorted by departure airport or arrival airport so that traffic demand for any desired terminal area and associated transition area can be examined.

Although the data available from the Peak Day IFR tape provide valuable inputs to route structure and transition area design development, it may be

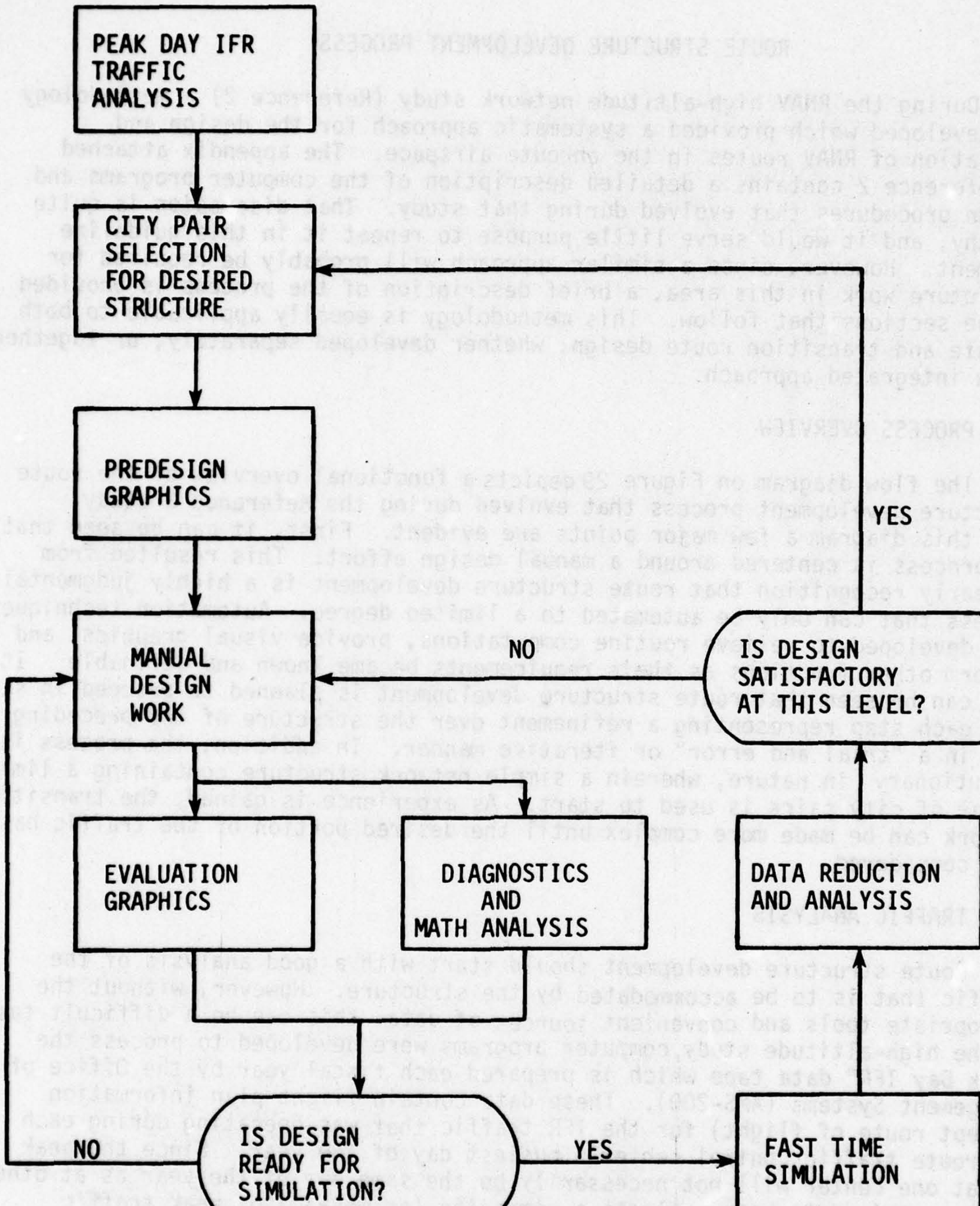


Figure 29 Transition Route Design Process

desirable to examine a wider range of traffic conditions. It may also be necessary to know the routings that are presently being flown and how these routings change under different weather conditions. In particular, if the RNAV structures are to be evaluated for potential benefits, then present routings are required to serve as baseline data. Comprehensive data to satisfy these and other needs could be derived from the on-going NAS recording system. However, convenient methods to collect and reduce these data to readily usable form for route structure development are not presently available. This situation could be corrected however, through development of the appropriate computer software.

An alternative approach for traffic analysis would be to collect flight progress strips from each of the air route traffic control centers. Although the reduction of these data is a laborious, manual process, it may be necessary if adequate data processing of the NAS data is not available to support the route structure development activity.

Regardless of how the traffic analysis function is accomplished, the essential point is that this is a necessary first step in both enroute and transition route structure development. Subsequent steps shown on Figure 29 will have little meaning without some sort of traffic analysis capability.

6.3 CITY PAIR SELECTION

As indicated earlier, transition route structure development should start with the design of a simple structure and, as more experience and insight are gained, the design can then progress through increasing degrees of complexity. This evolutionary approach is accomplished through appropriate selection of city pairs between which RNAV routes and transitions serving these routes will be constructed. In the RNAV high-altitude study the selection levels were set at 50, 150, and 250 city pairs. The specific pairs selected were based on the daily exchange of traffic as derived from the Peak Day IFR tape, starting with the heaviest exchange and working down. In the level 50 structure the traffic exchange rate was approximately 25 or more flights per day, in the level 150 structure the exchange rate was reduced to around 15 or more, and in the level 250 structure further reduction was made to about 10 or more flights per day. As pointed out in Reference 2, however, pairs with lower exchange rates were added to each selected set where such addition could be made without impacting the basic structure for that level. The inclusion of these added airports is a particularly important consideration in the development of transition routes since transition areas around a selected (major) airport must take into account traffic flows into and out of other airports in proximity to the selected airport.

6.4 PREDESIGN GRAPHICS

In the main, predesign graphics serve two main purposes. First, they provide a pictorial representation of the traffic demand between the selected city pairs, and second, they provide worksheets for route structure design. After the design for the initial level has been completed, these graphics also show the geometric relationships between the previously designed structure

and the traffic demand being added by the additional city pairs. In this way obvious cases can be detected where the designed structure can accommodate the added traffic, or where only minor modifications are required. Areas where additional routes impact on previously designed routes can also be detected by this approach.

The form and content of the predesign graphics naturally depends upon the data processing capabilities available to the transition route structure design activity. In the RNAV high-altitude network study, computer programs were developed which generated CALCOMP plots for predesign worksheets. On these plots traffic demand was presented as straight lines between the selected set of city pairs and, since a gnomonic projection was used, these straight lines represented direct great circle routes. These lines were truncated at a point 100 miles from the terminal center (120 miles if the terminal was a metroplex) in order to provide a starting point for transition route design. (As will be seen in subsequent sections the ultimate transition route starting points will be derived through consideration of several factors peculiar to each terminal area). In addition to traffic demand lines these graphics could present combinations of the following data under user options:

a. Previously designed RNAV routes
b. Existing VOR routes
c. Terminal arrival and departure routes
d. Special use airspace
e. ATC sector boundaries
f. Airport symbols and identifiers
g. NAVAIDS
h. Lines of demarcation to reflect conceptual terminal area boundaries (see Section 1.3)

In addition to the content of the predesign graphics, other options were available to the user, including area size, scale, multicolor selection, and a wide range of detail data.

It is recognized that other graphics techniques than those described in Reference 2 could be developed for transition route development. However, the main point to be made here is that effective route structure development requires a convenient and efficient graphics capability.

6.5 MANUAL DESIGN

In general, manual design work in route structure design consists of applying design concepts and principles which are developed in an evolutionary manner through trial and error. Several of the concepts that evolved from the Reference 2 study are discussed in subsequent sections of this guideline document as they pertain to transition routes. The actual procedures that must be followed in constructing route structures for subsequent evaluation will depend upon the automation aids and other tools available to the transition route design activity. As a starting point, it is suggested that the software and design procedures described in the appendix to Reference 2 be examined for possible application, or as a minimum, for guidance in the development of the necessary tools.

6.6 DIAGNOSTICS AND EVALUATION

Following each manual design step the transition route structure should be examined visually to detect obvious design errors. In addition, through operational judgment, areas can be identified where undesirable traffic problems may result. To a limited degree the structure can be manually evaluated against design criteria, such as for centerline spacing, intersection angles, and similar geometrical factors. More detailed diagnostics and design analyses require supporting computer software. In the Reference 2 study, the evaluation graphics were developed by the same software as the predesign graphics and, in addition, computer programs were developed which provided the following data:

a. Discontinuities between route segments
b. Route nomenclature errors
c. Terminal boundary descriptions
d. Violations of design criteria
e. Improper use of entry/exit waypoints
f. Route mileage analysis
g. Intersection angle analysis and
h. Intersection and waypoint proximity analysis

6.7 FAST-TIME SIMULATION

It is difficult to envision effective transition route structure development without support of a fast-time simulation capability. By simulating the movement of representative aircraft through the network, potential operational problems can be detected which may otherwise go unnoticed until the structure has been implemented. The data from fast-time simulation will show areas where the potential conflict rate would be excessive and, further, will identify the nature of the conflicts which, in turn, may lead to design solutions. Furthermore, as designs are modified and new design concepts are developed, the simulation data will show the effectiveness of these changes. As the transition route structures become more complex, design errors and other problems become increasingly difficult to detect. Normally, data from simulation will help detect and resolve these situations. Also, if portions of the transition structure are to be simulated in real time prior to implementation, fast-time simulation can help identify which areas need to be examined in a real-time ATC environment.

7.0 TRANSITION AREA DATA REQUIREMENTS

As with terminal area route design, a comprehensive body of data needs to be assembled in conjunction with the design of RNAV transition routes. An outline of the types of data needed is presented in Table 4 along with some of the sources from which these data may be acquired. It should be noted that several of the sources listed are computer tapes; therefore, their use will require some level of data processing capability. Reference 2 describes how several of these tapes were processed and the resulting data applied to the design of high-altitude RNAV routes.

7.1 TRAFFIC DATA

From the discussion on the route structure development process (Section 6.0) it can be seen that effective transition route design in predicated upon thorough knowledge of the traffic to be accommodated. The daily traffic exchange rate between city pairs is used to systematically select traffic levels to be accommodated during each phase of the evolutionary development process. Also, when these traffic are represented by direct, great circle lines between the city pairs, guidance is provided as to which traffic can be merged into common flows which, in turn, form the genesis of the route structure design with which the transition structure must interface. If the daily exchange rates can be broken down to hourly rates, then route and segment loading estimates can be used as further guidance in the design, particularly where multiple routes or route segments are required. In addition to traffic exchange rates, it is necessary to know the predominant cruising altitudes and aircraft types of the traffic to be accommodated by the transition routes under development. These data, together with information from the terminal area design activity, are used to derive transition route lengths and other geometrical characteristics of the transition area structure.

7.2 AIRPORT/TERMINAL AREA DATA

In general, airport and terminal area data requirements for transition route design are about the same as for terminal route design as described in Section 2.0 and, therefore, an initial source of these data would be the various activities involved in the terminal area work. However, the transition route design activity may require data for airports and terminal areas for which the terminal route design activity has not assembled the necessary information. In these cases, the required data can normally be derived from the sources listed in Table 4. Airport latitude and longitude coordinates are needed to plot the airports on the design worksheets and also to formulate the network of great circle routes representing the traffic demand to be accommodated by the routes with which the transition structure must interface. Also, if not already accomplished by the terminal route design activity, primary and satellite airport data are needed in order to derive starting point locations for the arrival and departure waypoints on the terminal airspace perimeter. Obviously, traffic, terrain and other factors should also be considered along with airport locations when deriving these initial way-

Table 4 Transition Area Data Sources

A. TRAFFIC DATA

1. Peak Day IFR Data Tape (AMS-200)
2. NAS System Analysis and Recording (SAR) Tapes
3. ARTS Extraction Tapes
4. Flight Progress Strips
5. Official Airline Guide, North American Edition
6. Reuben H. Donnelley Tapes

B. AIRPORT/TERMINAL AREA DATA

1. FAA Airport Master Tape
2. Airman's Information Manual, Parts 2 and 4
3. DOD FLIP - Enroute IFR Supplement
4. DOD FLIP - Instrument Approach Procedures (9 Vols.)
5. VFR Terminal Area Charts

C. ROUTE DATA

1. NAS SAR Tapes
2. Flight Progress Strips
3. NAS Prefiled Flight Plan Store
4. Airman's Information Manual, Part 3
5. Standard Instrument Departures (SIDS) Publications
6. Standard Terminal Arrival Routes (STARS) Publications
7. Facility/Facility Letters of Agreement
8. Facility Standard Operating Procedures

D. AIRWAY/FIX DATA

1. Controller Chart Supplement Subscriber Tape
2. Controller Charts
3. Controller Chart Supplement - Sections 1 through 3
4. Enroute Aeronautical Charts (Low, High, RNAV, Area)
5. Sectional Aeronautical Charts
6. IFR/VFR Wall Planning Charts
7. FAA Handbook 7350.4 - Location Identifiers

E. SPECIAL USE AIRSPACE

1. Federal Register, Title 14 CFR Parts 71, 73, 75
2. IFR/VFR Wall Planning Charts
3. Enroute Aeronautical Charts
4. Airman's Information Manual, Part 4

F. TERRAIN DATA

1. Sectional Aeronautical Charts
2. VFR Terminal Area Charts
3. Topographic Center, Defense Mapping Agency

G. NAVAID COVERAGE

1. FAA NAVAIDS Master Tape
2. Aeronautical Charts and Publications
3. Report No. FAA-RD-76-210; NAFEC
4. RACO Flight Check Data

H. SECTOR BOUNDARIES

1. NAS System Program Tape (SPT)
2. ARTCC Files

I. AIRCRAFT PERFORMANCE

1. Manufacturers Aircraft Performance Reports
2. Pilots Manuals
3. Airline Operations Offices

J. TENTATIVE RNAV ARRIVAL/DEPARTURE WAYPOINT CONFIGURATIONS

1. Terminal Area RNAV Route Design Activities

point configurations. When starting route design, it is also desirable to know the primary arrival/departure runway configurations for each airport in the terminal area. Consideration of these internal flows during transition route design will reduce the compatibility problems when terminal and transition routes are integrated into a common route system.

7.3 ROUTE DATA

An analysis of the routings currently being flown in the National Airspace System is an important prerequisite to effective transition route design. These routings have evolved through years of operational experience and it is necessary to understand the underlying factors that contributed to their configuration. Many of these factors are not directly related to the navigation function; therefore, solutions to problem areas in the present system should provide insight for equal or better solutions in an RNAV environment. Further, major changes to the traffic flow patterns may result from the RNAV transition route design and it would be difficult to defend such changes without a good knowledge base of the present system.

Of the route data sources listed in Table 4, the NAS SAR tapes provide the most comprehensive information. From these tapes flight plan and ATC clearance information can be derived along with time correlated radar track data. The impact of weather, traffic loads, and other factors can also be determined from analysis of the SAR tapes. However, the necessary data processing of these tapes requires a substantial amount of software development. If the needed programming support is not available to the transition route design activity, route data to a limited degree can be derived manually from the other sources listed in Table 4.

7.4 AIRWAY/FIX DATA

The primary use of the airway/fix data base in RNAV route development is for fix-to-fix definition of route data contained in flight plans and ATC clearances. In the present system, navigational data is separated into three distinct structures; i.e., low-altitude Federal airways, high-altitude jet routes, and high-altitude RNAV routes. Flight plans and ATC clearances, on the other hand, may contain various combinations of these structures, normally expressed by the names of the airways, jet routes and/or direct paths to be flown. Therefore, to define flight plans and clearances in a form suitable for plotting and other analysis requires considerable search and cross-referencing of the three comprehensive data bases. This function is amenable to data processing and the "Controller Chart Supplement Subscriber" tape, which is updated every 56 days, is an excellent source of the required data. Software development to perform this function is relatively minor and it is suggested that this approach be taken in support of RNAV route and transition structure development.

7.5 SPECIAL USE AIRSPACE

As with any route design, the impact on restricted areas and other special use airspace must be identified. For RNAV transition route design this can best be accomplished by plotting the appropriate special use airspace

on the design worksheets. With a computer-aided design system, such as the one described in Reference 2, the task is reduced to inputting the coordinates contained in the Federal Register and the computer program then selects the appropriate area for plotting. For enroute route design this computer assistance substantially reduced the workload of the design activity; however, for the transition area the function can be performed manually without undue workload.

7.6 TERRAIN DATA

In mountainous areas it is necessary to consider surrounding terrain when designing transition route structures. Although terrain peaks and topographic contours are depicted on sectional charts, it is difficult to accurately transpose these data to the design worksheets. Since sectional charts, themselves, are not good worksheets, there is need for improvement in this area. The Topographic Center of the Defense Mapping Agency (DMA) has been in the process for some time of digitizing topographic contour data of the United States and storing these data on magnetic tape. The Electromagetic Compatibility Analysis Center (ECAC), Annapolis, Maryland, has applied the DMA data to a wide range of activities for the Department of Defense and the FAA. In Report No. FAA-RD-76-210, NAFEC described how these data could be applied to derive NAVAID coverage (see next section). From review of these uses of the DMA topographic data, it seems apparent that, with only a modest amount of computer programming, the data could have direct application to transition and enroute RNAV route design. Obviously, this application would be in concert with NAVAID coverage, discussed in the next section.

7.7 NAVAID COVERAGE

Before an RNAV structure can be considered implementable, it must be checked for NAVAID coverage. These checks include signal coverage along the route centerline as well as over the expected offset distances. In addition, navigational error data must be examined based on tangent point and along track distances relevant to the route and the supporting NAVAIDS. On a small scale, such as an individual transition area, these checks can be accomplished manually, provided adequate NAVAID coverage contours are available. On a larger scale, such as for the total U.S., this manual process could inundate the network design activity. The NAFEC report listed in Table 4, describes a computer-aided methodology which utilizes the DMA topographic data to derive NAVAID coverage contours. The system also checks a route structure against these contours to determine gaps in coverage, route width data, and other information associated with NAVAID support of RNAV routes. In addition, the methodology can validate and/or replace terrain-derived coverage through use of random coverage (RACO) plots, developed from flight checks by the Aeronautical Center, Oklahoma City, Oklahoma.

7.8 SECTOR BOUNDARIES

It is assumed that, prior to implementation of an RNAV structure, a thorough treatment should be given to the relationship between the transition route structure and sector configuration. Areas of incompatibility will

probably be resolved through system trade-offs, such as realignment of sector boundaries, modifications to the route structure, or combinations of both. In addition to sector workload, the following factors are important:

1. Distances along routes between sector entry and exit points,
2. Angles at which route segments cross sector boundaries,
3. Proximity of routes with respect to sector boundaries,
4. The number and complexity of routes within a sector, and
5. Cases where a route enters and/or leaves a sector more than once.

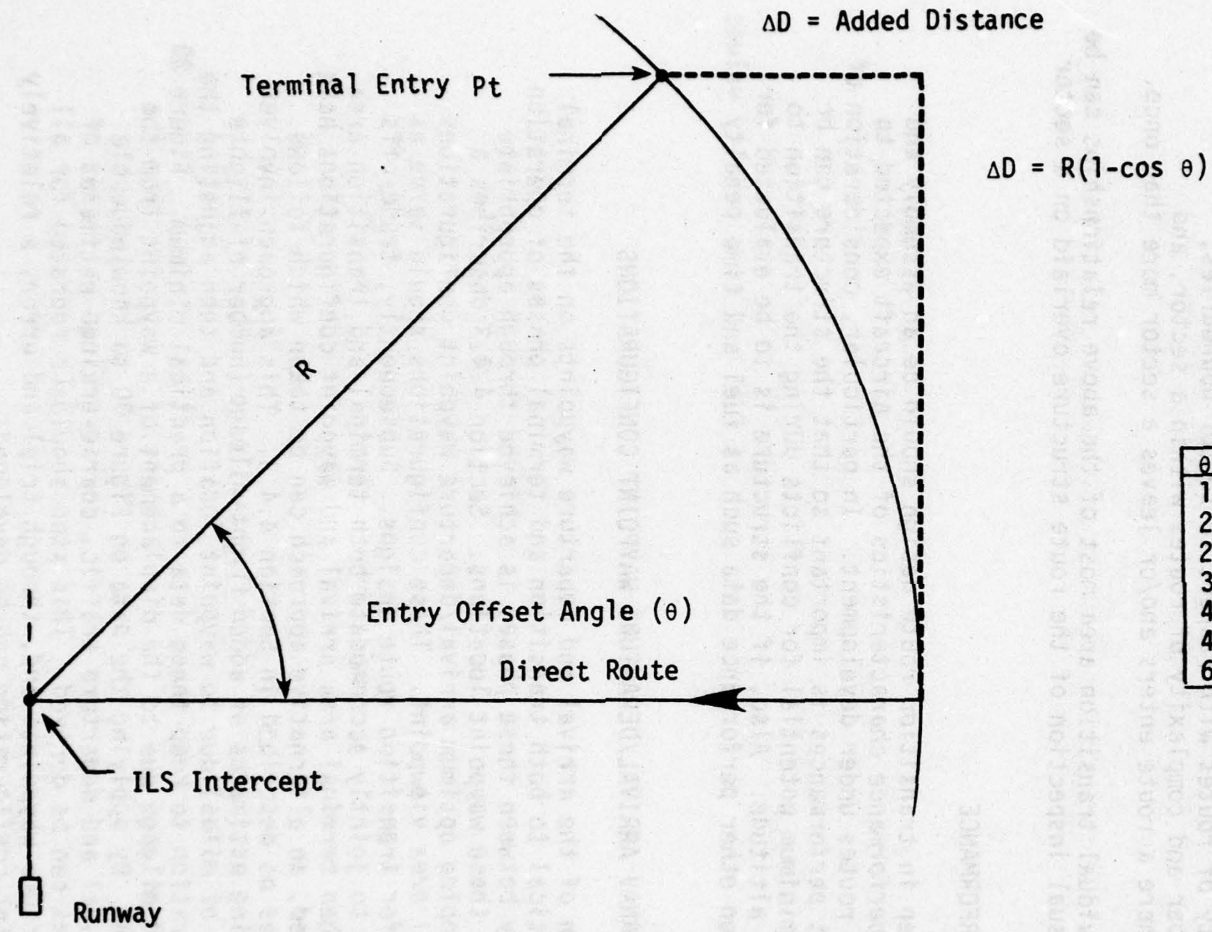
For an individual transition area most of the above relationships can be determined by visual inspection of the route structure overlaid on a sector map.

7.9 AIRCRAFT PERFORMANCE

An early step in transition route design should be an assembly and analysis of the performance characteristics of the aircraft expected to operate over the routes under development. In particular, consideration of climb and descent performances is important so that the structure can be designed with a minimum potential for conflicts during the transition to and from enroute altitude. Also, if the structure is to be evaluated for user benefits then other performance data such as fuel and time penalty values are needed.

7.10 TENTATIVE RNAV ARRIVAL/DEPARTURE WAYPOINT CONFIGURATIONS

The location of the arrival and departure waypoints on the terminal perimeter is critical to both transition and terminal phases of operation and compatibility between these phases is achieved through appropriate configuration of these waypoint locations. Section 4.4.3 describes a method for developing optimum arrival/departure waypoint configurations from the terminal area viewpoint. These configurations should serve as starting points for transition route designs. Subsequently, trade-offs will be required to jointly accommodate both terminal and transition area requirements. When terminal area arrival and waypoint configurations have not been developed, an alternative approach can be taken which follows similar procedures as described in Section 4.4.3. This approach involves manually developing estimates of added flight-mileage (number of flights times the number of miles) due to waypoint location and then adjusting the waypoint configuration to keep these data to a practical minimum. Figure 30 depicts the added mileage due to the displacement of a waypoint from the most direct route. By applying the data on Figure 30 to knowledgeable estimates of arrival and departure traffic, coarse-grained estimates of added flight-miles can be derived. This step should be repeated for all arrival and departure waypoints and, through trial and error, a relatively good starting point configuration can be developed.



R=50

θ°	ΔD
15	1.7
20	3.0
25	4.7
30	6.7
40	11.7
45	14.6
60	25.0

Figure 30 Added Mileage Due to Entry Point Displacement

Again, it should be pointed out that the foregoing refers to an initial configuration for the start of transition route design. When other factors are considered during the route structure development process, further adjustments will undoubtedly be required. The inherent flexibility in RNAV simplifies these changes. However, it is important not to let the ease of relocating RNAV waypoints obscure the need to always check for potential penalties that may be imposed on the user of the system. It is recommended that computer-aided methodology be applied to the final enroute and transition route design evaluation when the enroute and transition structure have been interfaced as a total design.

8.0 DESIGN CONCEPTS AND CONSIDERATIONS

As discussed earlier, provision for accommodating the transition phase of operations should be an integral part of the enroute structure development. It may turn out, therefore, that in certain areas transition requirements will exert the major influence on the design of the enroute structure.

Generally, however, the most effective application of RNAV will evolve through design trade-offs which take into account the overall requirements of enroute, transition, and terminal. In any event, the design considerations discussed below are applicable whether or not the end product results in specially designed enroute airways to accommodate transition or in separate transition routings. As will be shown, the latter may be of three forms: (1) alternate routes on the charted enroute structure, (2) uncharted routes to be flown as a parallel offset from a charted route, (3) graphic and/or textual descriptions associated with SIDS and STARS.

8.1 ONE-WAY ROUTING

It was demonstrated by fast-time simulation [Ref.2] that the use of one-way route segments is an effective means to accommodate extended climb and descent to and from the assigned enroute altitude. To the extent practicable, this practice is followed in the present VOR airway environment. However, restrictions in effecting one-way climb and descents frequently arise due to the lack of flexibility in the VOR structure. In an RNAV structure there is adequate flexibility; therefore, the design should provide for extensive use of one-way transition routings. This may be accomplished in different ways, depending upon the area. In some areas it may be necessary to designate portions of the charted enroute structure as single direction segments; while in other areas one-way routings may be accomplished by especially designed SIDs and STARs. Use of the parallel offset feature of RNAV avionics is another way that one-way transition may be effected. Each of these methods are dependent upon, and influence various parts of the enroute and terminal structures.

8.2 RNAV SIDS AND STARS

For effective RNAV implementation it is assumed that RNAV SIDS and STARS will consist of segments which form a navigable path between the runway and the enroute altitude. This discussion, however, pertains only to that portion which lies outside the terminal; i.e., between the arrival or departure waypoint on the terminal perimeter and the point where aircraft reach or descend from enroute altitude. Also, it is not intended that the routings described herein would only be of the type depicted in special SID/STAR publications. It may turn out that some route segments designed for transition will be integrated into the charted enroute structure. In this case they could be considered as alternate routes which are used to facilitate climb and descent.

8.2.1 Number of Waypoints

In designing RNAV SIDs and STARs it is important to keep the number of waypoints to a minimum in order not to impose unrealistic requirements on RNAV avionics and/or excessive workload on the pilot. If possible, it is operationally better to enter or prestore the total SID or STAR prior to

entering the route due to the possibility of blunders and other factors. Since the geometry within the terminal area may require considerable turning, it follows that the geometry in the transition area should be as simple as possible so that the total number of waypoints on the SID or STAR including transition is reasonable. A minimum number of segments is also desirable due to NAS computer storage requirements and video map clutter. In addition, use of the RNAV offset feature to resolve conflicts is more effective in an uncomplicated structure.

8.2.2 Parallel Segments

Wherever practicable, RNAV SID and STAR transition segments should be parallel with adjacent segments. This not only uses the airspace more efficiently, but also enhances use of the RNAV parallel offset to resolve conflicts. For example, if the centerlines of two parallel segments are two or more airway widths apart, an aircraft on a parallel offset from one segment will not interact with aircraft on the other segment. This is particularly useful in overtake conflict situations which may require considerable time to resolve. Where adjacent segments converge it may be more difficult to determine when procedural separation is lost between the aircraft on the offset and aircraft on the converging segment.

8.2.3 Spur Segments

In uncomplicated airspace, the transition part of RNAV SIDS and STARS may take the form of single spur segments between a waypoint on the terminal perimeter and a waypoint on the charted enroute airway. In this type of airspace, one waypoint on a two-way enroute airway will normally serve for both climb and descent segments. Although the location of the enroute waypoint is not critical, a good practice is to place the waypoint where arrival aircraft would normally start descent to reach the terminal waypoint at the desired altitude. For convenience, a descent profile of 400 feet per mile can be used to initially locate the enroute waypoint. Departures may not reach altitude at that waypoint; however, the parallel offset may be used to extend the merge point on the airway, if required to avoid traffic conflict.

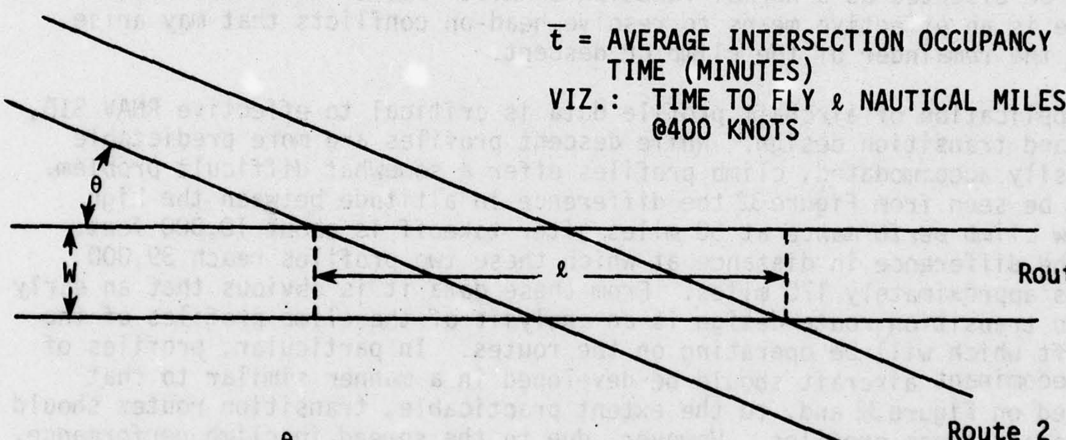
8.2.4 Special SID/STAR Design

In more complicated airspace, RNAV SID and STAR transition routes will require special tailoring as indicated in the examples presented later. Nevertheless, in the transition area the element of simplicity should be maintained to the extent practicable. Wherever possible the number of segments on a transition route should be kept to three or less. Also, the geometry should make maximum use of RNAV flexibility so that the potential for traffic interaction is minimized. In addition to the use of parallel segments wherever possible, the structure should have a minimum number of intersections. Where climb and descent segments intersect, the intersection point should be located where altitude separation would normally exist based on aircraft climb and descent profiles. If this is not feasible, then the intersection angle should be as large as possible (close to 45°) so as to minimize the elapsed time of altitude restrictions that may be required. In other cases, intersection and merge/demerge points may require smaller angles. However, as shown on Figure 31, the occupancy time at an intersection increases

ASSUMPTIONS: $\overline{W} = 8$ nm
$\overline{V} = 400$ knots

$\theta°$	ℓ	$\overline{t}$	$\overline{V}_R$
5	183.2	27.5	35
10	91.4	13.7	70
15	60.7	9.1	104
30	29.9	4.5	207
45	19.3	2.9	306
60	13.8	2.1	400
75	10.4	1.6	487
90	8.0	1.2	566

$\overline{t}$ = AVERAGE INTERSECTION OCCUPANCY TIME (MINUTES)
VIZ.: TIME TO FLY ℓ NAUTICAL MILES @400 KNOTS



$$\ell = W \cot \frac{\theta}{2} \quad \text{(nm)}$$

$$\overline{V}_R = \overline{V}\sqrt{2(1-\cos\theta)} \quad \text{(KNOTS)}$$

WHERE: $\overline{V}_R$ = AVERAGE CLOSURE RATE
$\overline{V}$ = AVERAGE AIRCRAFT VELOCITY (KNOTS)

Figure 31 Route Intersection Geometry

sharply as the angle decreases, especially below 10°. Therefore, to reduce the amount of time that procedural separation is lost, angles of 10° or more should be maintained.

As a design objective, RNAV SID and STAR transition routes should provide a path for as much of the climb/descent phase of operations as is possible when all other factors are considered. The length of the transition part of SIDs and STARs will therefore depend upon aircraft performance, commonly assigned enroute altitude, and the normal altitude at the arrival and departure waypoints on the terminal perimeter. The latter is a function of route length within the terminal as well as aircraft performance, altitude restrictions, and other requirements (See also Section 4.7.4 regarding high performance departure envelopes). Enroute altitude in the upper airspace depends primarily on the distance between terminals. In some areas, such as between New York and Chicago, enroute altitude assignment along the charted airways may cover the total altitude spectrum of the upper airspace. The transition route design should accommodate the highest of the frequently assigned enroute altitudes for the airways served by the appropriate SID or STAR. Remaining transition to and from infrequently used higher altitudes should be effected as a normal function of ATC. Use of the RNAV offset feature is an effective means to resolve head-on conflicts that may arise during the remainder of the climb or descent.

Application of aircraft profile data is critical to effective RNAV SID, STAR, and transition design. While descent profiles are more predictable and easily accommodated, climb profiles offer a somewhat difficult problem. As can be seen from Figure 32 the difference in altitude between the high and low climb performance at 50 miles after takeoff is about 10,000 feet. Also the difference in distance at which these two profiles reach 39,000 feet is approximately 170 miles. From these data it is obvious that an early step in transition route design is an analysis of the climb profiles of the aircraft which will be operating on the routes. In particular, profiles of the predominant aircraft should be developed in a manner similar to that depicted on Figure 32 and, to the extent practicable, transition routes should accommodate these profiles. However, due to the spread in climb performance, trade-offs will normally be required. Also, transition routes that would accommodate the B747 profile to 39,000 feet could have a severe impact on other transition routes as well as on the enroute structure. Required shortening of the departure transition routes should not impose a serious problem since the remaining climb will be effected in lighter traffic conditions and the RNAV offset is available for conflict resolution.

There is no intent in the above discussion to imply that RNAV transition routes are 3-dimensional routes requiring vertical area navigation (VNAV). Traffic permitting, fast climbers may reach assigned enroute altitude well before completing the departure transition route. Further, if there is an operational advantage, the enroute structure may be joined at this point upon clearance by ATC. Slow climbers may complete the departure transition route well below the assigned altitude and substantial distance may be required after joining the enroute structure before the assigned altitude is reached. Again, use of the RNAV offset to resolve conflicts facilitates enroute climbing operations.

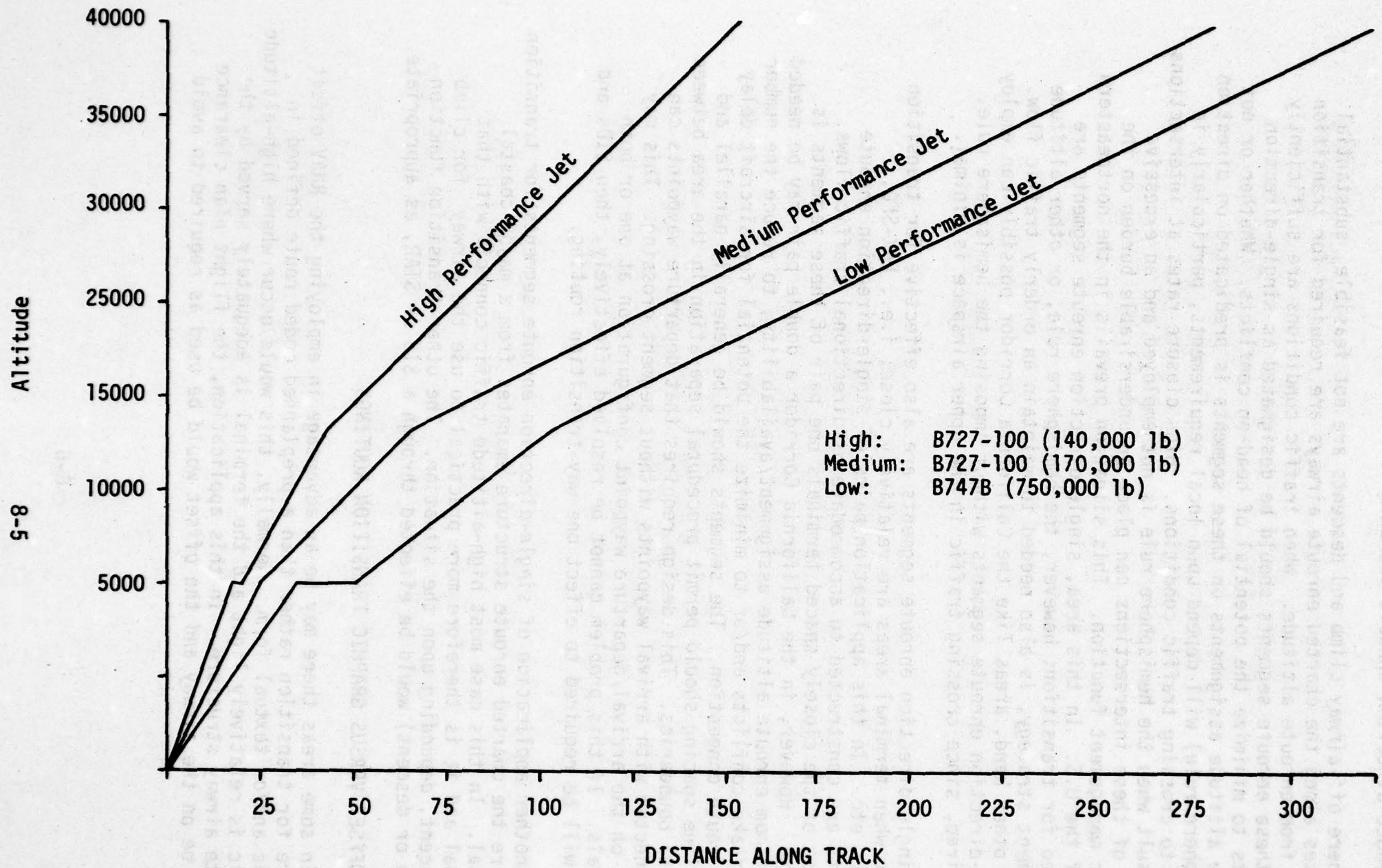


Figure 32 Typical Climb Profiles

8.3 SINGLE-DIRECTION ENROUTE SEGMENTS

Where off-airway climb and descents are not feasible, substantial distances along the charted enroute airways are required for transition to and from enroute altitude. When traffic conditions are sufficiently heavy these enroute segments should be designated as single-direction segments to minimize the potential of head-on conflicts. Whether or not enroute altitude assignments on these segments is predicated on direction (hemisphere rule) will depend upon local requirements, particularly in regard to crossing traffic conditions. High closure rates at intersections can result when the hemisphere rule is not employed and an excessive number of these intersections can place an undersirable burden on the traffic management function. This situation prevails in the northeastern part of the U.S. In this area, single-direction enroute segments are required for transition; however, the hemisphere rule, or other altitude assignment strategy, is also needed to maintain an orderly traffic flow. On the other hand, areas like the California Corridor possibly can employ single-direction enroute segments without imposing the hemisphere rule, if desired, since crossing traffic in the upper airspace is minimal.

Single-direction enroute segments are also effective for transition routing when terminal areas are relatively close; i.e., LAX-SFO, MKC-STL, etc. In this application pairs of single-direction enroute segments are constructed to accommodate bi-directional traffic flows. For most of the closely spaced terminals one pair of these segments is adequate. However, in the California Corridor a double pair may be needed for optimum enroute altitude assignment/availability, to reduce the number of overtake conflicts and/or to minimize the potential for aircraft delay due to route congestion. The segments should be generally parallel and centerline spacing should permit procedural separation in the area between terminal boundaries. This design requires that departure waypoints can be connected with arrival waypoints without segment crossing. This may impact on the arrival/departure waypoint configuration at one or both terminals. If this problem cannot be resolved effectively, then SIDs and STARs will be required to effect one-way transition routing.

Another application of single-direction enroute segments for transition is where the charted enroute structure emanates from a major coastal terminal. In this case most high-altitude traffic connects with that terminal and it is therefore more practical to use the airway for climb or descent, depending upon the situation. The other transition function (climb or descent) would be effected through a SID or STAR, as appropriate.

8.4 OFFSET VERSUS GRAPHIC TRANSITION ROUTINGS

In some areas there may be an advantage in employing the RNAV offset feature for transition rather than a preplanned coded route defined in graphic and/or textual form. Normally, this would occur where high-altitude traffic is relatively light and the terminal is adequately served by the enroute airway structure. In this application, the flight plan clearance would be on the airway and the offset would be used as required to avoid

conflict. It should be noted however, that the same amount of airspace in the enroute area is required as if the routings were pre-defined in a SID or STAR transition. If use of the offset becomes standard practice for transition, then it is better to pre-define and publish the route and reserve the offset for conflict resolution.

8.5 INTERACTION WITH LOW-ALTITUDE STRUCTURE

At some departure or arrival waypoints the transitioning flight's altitude may be well below 18,000 feet, requiring substantial distances for climb or descent while in the low-altitude airway structure. Where this is predicted to occur, the design for high-altitude transition routes should be closely integrated with the low-altitude airway structure development in order to reduce the potential for traffic interactions. In these areas, the high-altitude transition routes should either overlie corresponding low-altitude airway segments, or the latter should be included as part of the transition route description, if at all feasible.

8.6 INTERFACE WITH HIGH-ALTITUDE AIRWAYS WHICH CROSS TERMINAL AIRSPACE

It is assumed that the charted high-altitude RNAV airway structure should provide a continuous path across terminal airspace for overflying traffic. That is, the airway should not end at a waypoint on the terminal perimeter, but should either continue beyond the terminal in the same general direction or should connect with other airways through a common waypoint. As shown on Figure 33, transition routes may interface with crossing airways in several different ways. Example A is the most common and straightforward interface geometry. In this example, two pairs of SID/STAR transition routes connect with a two-way airway, accommodating arrivals, departures, and overs in both directions. However, the traffic and airway congestion near waypoints E and W may be such that the potential for conflicts is excessive and resolution by RNAV offset is restricted. Examples B and C offer potential design solutions for this situation. In these geometries, overflights either follow the same routing to/from the terminal perimeter as transitioning aircraft, or merge/diverge rapidly at waypoints E and W. In example B the added distance is equalized for both directions; however, the choice between the two geometries will depend primarily on the arrival/departure waypoint configuration on the terminal perimeter. In these cases the transtion routes would be integrated into the charted enroute structue. It should be noted that, traffic permitting, aircraft can be cleared to fly direct between waypoints E and W; therefore, these designs offer a strategic method for conflict avoidance with the provision for route shortening during periods of lower controller workload. Example D depicts the case where single-direction enroute segments are used for transition and enroute flight between terminals that are relatively close. The segments are basically parallel and the centerline spacing provides for procedural separation between terminal boundaries. Obviously, there may be several variations to the geometry depicted on Example D. The two-way crossing airways may be located outside the single-direction segments rather than between segments as shown on Figure 33. Also, a double pair of single-direction segments may be required due to traffic between the terminals. In this case location of the crossing airway would depend upon route mileage, arrival/departure waypoint configurations, potential

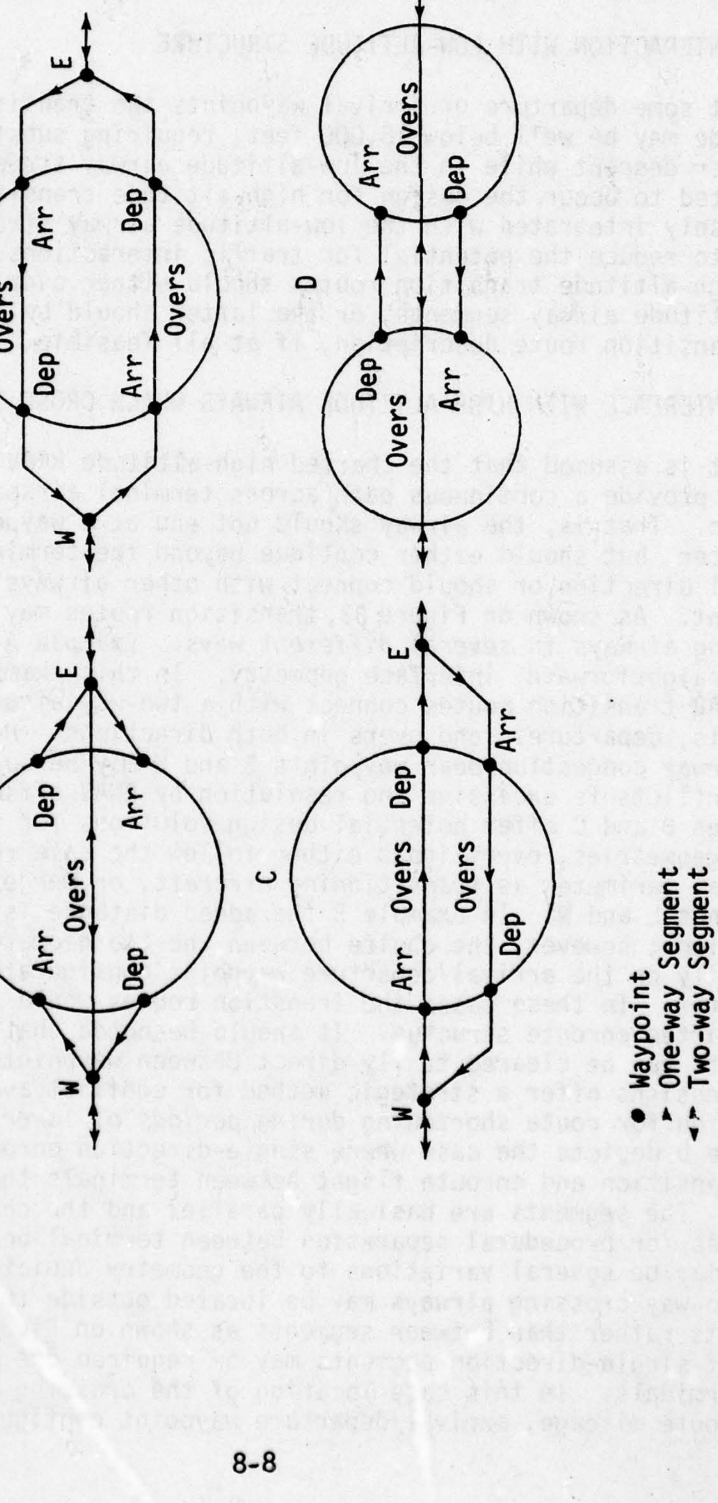


Figure 33 Interface between Transition and Over Traffic

traffic conflicts, and other factors. Also, if consecutive pairs of closely spaced terminals lie on nearly the same bearing, the two-way airway may be replaced by a pair of single-direction airways which accommodate enroute and transitioning traffic between these terminal pairs. Consider, for example, the area from San Antonio (SAT) to Minneapolis (MSP) with intermediate terminals Dallas (DAL), Tulsa (TUL), and Kansas City (MKC). Starting from SAT the direct distances are 208, 209, 194, and 340 miles. Although the traffic between SAT and MSP may be light, the most efficient RNAV design would be a charted pair of single-direction airways accommodating enroute and transition traffic between a possible total of 10 airport pairs.

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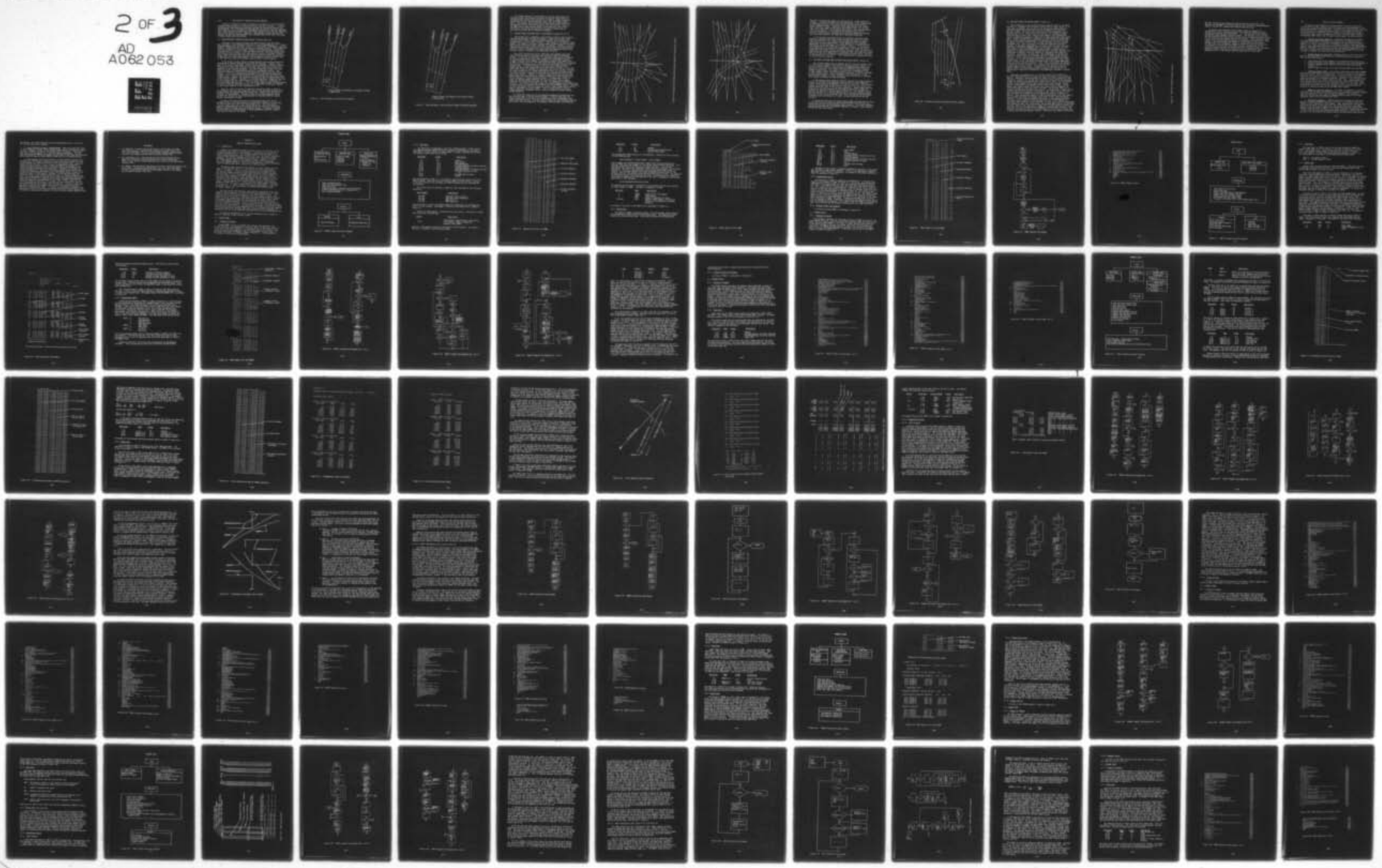


9.0 APPLICATION OF TRANSITION DESIGN CONCEPTS

Figures 34 through 39 present representative examples of how the foregoing concepts might be applied to achieve effective transition routings. It should be pointed out that these are conceptual designs for discussion purposes only and therefore, are not intended as implementation designs for the areas depicted. Also, there are many different ways that these concepts can be applied, depending upon a wide range of factors. Generally, these factors pertain to conditions peculiar to each area and therefore their consideration is not within the scope of these broader based guidelines.

9.1 MIAMI NORTHEAST TRANSITION AREA CONCEPT (Figures 34 and 35)

The great circle bearings between the Miami terminal area and several major terminals in the Northeast lie within an arc of approximately 15°. Traffic exchange between Miami and these cities (i.e., Washington, Philadelphia, New York, Boston) is moderately heavy and continues to increase, annually. The predominate cruising altitudes are in the upper stratum of the high-altitude airspace and crossing traffic is minimal in the area where aircraft transition between these altitudes and the altitude at the entry and exit points of the Miami terminal area. These conditions make this area ideally suited for effective application of RNAV which can reduce the potential for overtake and head-on conflicts and, at the same time, keep route mileages close to great circle distances.

In the design concepts shown on Figures 34 and 35, four enroute airways are constructed to connect southern Florida with the Northeast. However, since most of the traffic using these airways would be entering or leaving the Miami terminal area rather than overflying the area, the airways are aligned with waypoints on the terminal perimeter. On Figure 34 the four airways are single direction south of the merge/demerge points to accommodate arrivals. Two departure transition routes are provided where each route serves two enroute airways. The six arrival/departure waypoints on the terminal perimeter are located so as to minimize the increase in flight-mileage over the direct route flight-mileage. However, this waypoint configuration may be objectionable from an ATC sector viewpoint. Therefore, an alternate approach is shown on Figure 35. In this concept, the two inner airways are single-direction, northbound, to form one common departure sector. This design may impose a small distance penalty on traffic using the outermost airways (i.e., Washington and Boston); however, it may be more amenable to the requirements of ATC.

The 2 to 1 ratio of arrival to departure transition routes is based on the assumption that the inter-departure interval from the Miami terminal would be more evenly distributed than the interarrival interval from the several terminals in the Northeast. Therefore, more arrival than departure routes at Miami are required to reduce the potential of overtake conflicts during descent from enroute altitude.

As shown, the transition routes are approximately 250 miles long to accommodate the slow climb performance of heavy jets; however, arrivals need not start descent until well past the demerge point. Also, the precise location of the waypoints at the northern end of the transition routes will depend on NAVAID coverage over the overwater airways. To maintain coverage the structure can be bent westward at the merge/demerge waypoints, without impairing efficiency of the design.

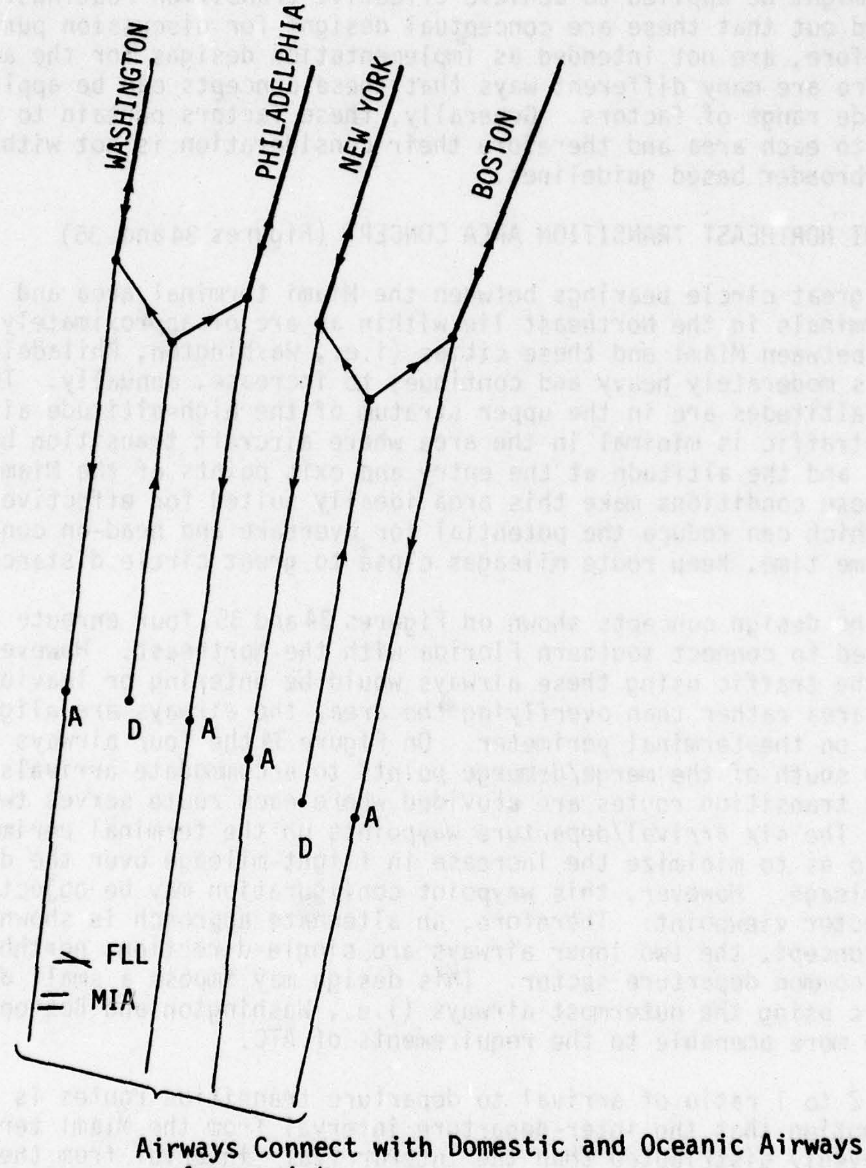
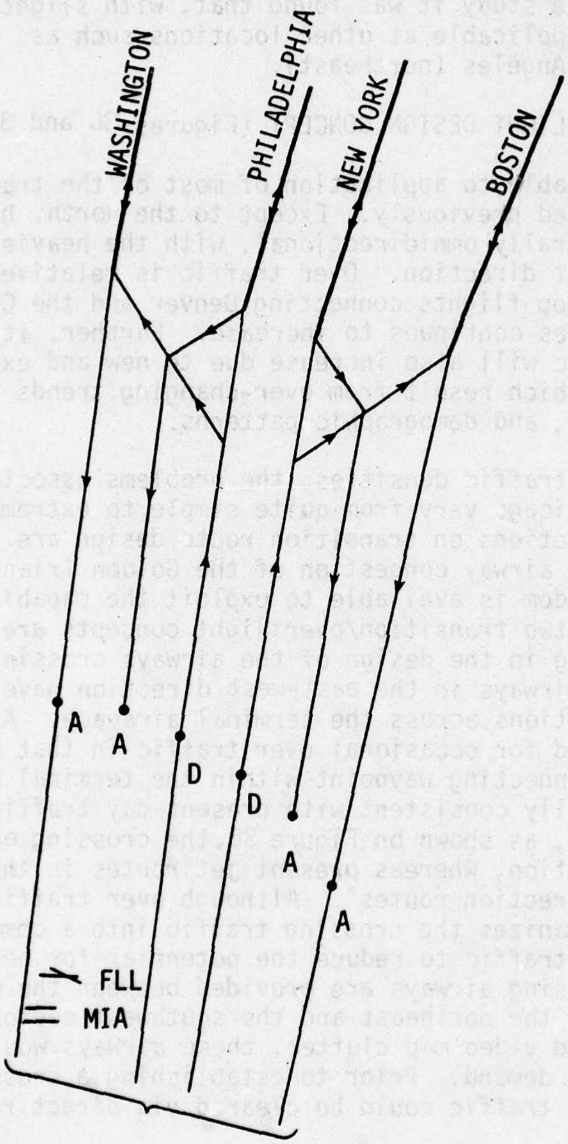


Figure 34 Miami Northeast Transition Area Concept



Airways Connect with Domestic and Oceanic Airways as Appropriate

Figure 35 Miami Northeast Transition Area Concept (Alternate Approach)

The "Miami" design is a good example of how the requirements for effective transition routings influence the enroute airway structure. The design also displays the capabilities of RNAV to reduce controller workload while still maintaining near direct routing between airport pairs. For example, the maximum added distance due to the location of the waypoints in the Figure 34 design was less than 3 miles. Also, in the RNAV enroute high-altitude study it was found that, with slight variations, this design was applicable at other locations such as San Francisco (east) and Los Angeles (northeast).

9.2 CHICAGO TRANSITION/OVERFLIGHT DESIGN CONCEPT (Figures 36 and 37)

The Chicago area is amenable to application of most of the transition route design concepts discussed previously. Except to the north, high-altitude traffic flow is generally omnidirectional, with the heaviest concentration in the east-west direction. Over traffic is relatively light; however, the number of non-stop flights connecting Denver and the California hubs to the northeastern cities continues to increase. Further, it can be expected that crossing traffic will also increase due to new and expanding city pair traffic exchanges which result from ever-changing trends in the nation's economic, ecological, and demographic patterns.

Due to the location and traffic densities, the problems associated with transition routing at Chicago vary from quite simple to extremely complex. To the east, restrictions on transition route design are imposed by the well-known traffic and airway congestion of the Golden Triangle. In other directions more freedom is available to exploit the capabilities of RNAV. In Figures 36 and 37 two transition/overflight concepts are presented; the principle difference being in the design of the airways crossing the terminal area. In Figure 36 airways in the east-west direction have established overflight connections across the terminal airspace. Also, one north-south airway is provided for occasional over traffic in that direction. All other airways end at a connecting waypoint within the terminal airspace. This design concept is basically consistent with present-day traffic flow across the terminal. However, as shown on Figure 36, the crossing east-west RNAV airways are single direction, whereas present jet routes in that area are not charted as "single direction routes". Although over traffic is light, the design concept organizes the crossing traffic into a common direction with transitioning traffic to reduce the potential for head-on conflicts. In Figure 37, crossing airways are provided between the northwest and southeast sectors and between the northeast and the southwest sectors. Obviously, to avoid unnecessary chart and video map clutter, these airways would only be added as warranted by traffic demand. Prior to establishing a crossing airway connection, infrequent traffic could be cleared via direct routing between waypoints.

The transition routes and arrival/departure waypoint configurations are basically the same in the two design concepts. It can be seen that the design establishes six arrival and six departure sectors as opposed to the present-day four and four. This was done to reduce the route mileage penalties that result from displacement of the waypoint from the great circle bearing

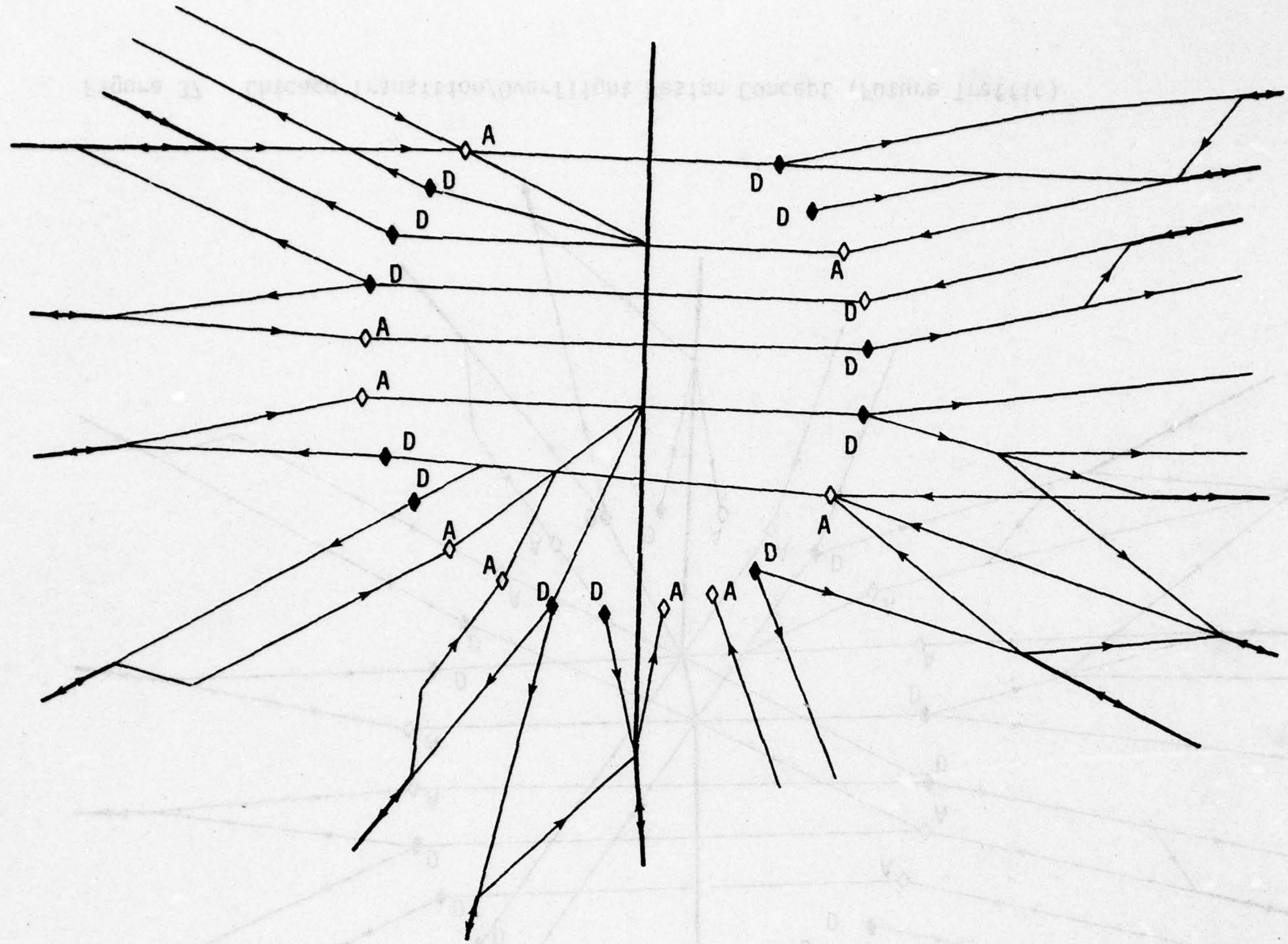


Figure 36 Chicago Transition/Overflight Design Concept (Present-Day Traffic)

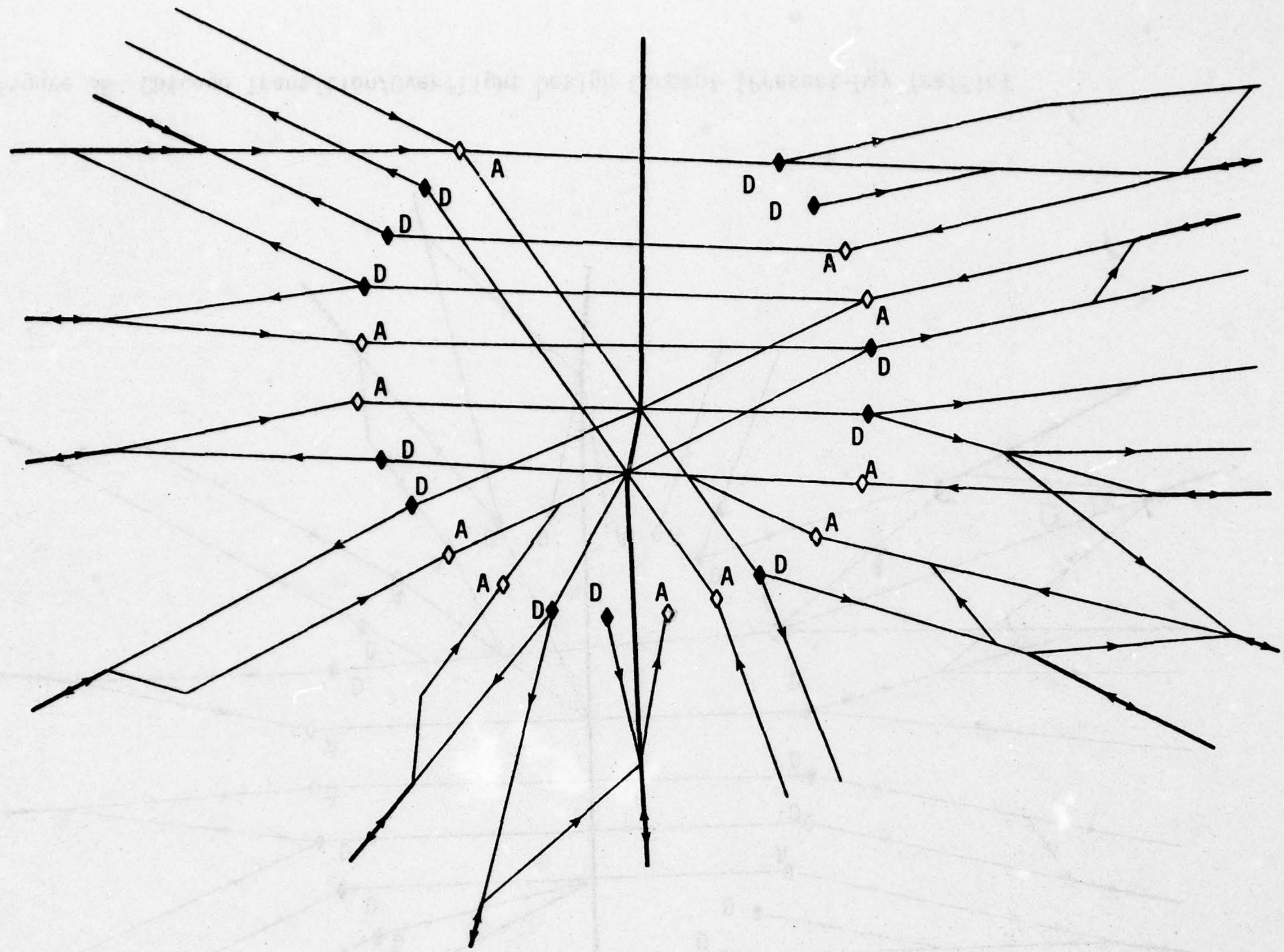


Figure 37 Chicago Transition/Overflight Design Concept (Future Traffic)

and also to minimize the amount of crossing traffic in the transition airspace. It should be noted that with present-day traffic demand, some of the waypoints would have minimum use while others would be quite heavily loaded at times. Therefore, these added sectors with lighter loads should not impose a problem for the terminal area. At the same time this traffic will not be unduly penalized and the transition flow will be more orderly. If problems in the terminal area arise as traffic in these sectors increases, then trade-offs between the terminal and transition areas will be required for equitable resolution.

It can be seen from Figure 36 that the different transition route geometries employed result from various assumptions about the traffic flow into and out of the Chicago area and about the enroute airways established to serve that traffic. These geometries are presented to demonstrate various conceptual solutions only since, in actual practice, the airways and traffic flow may be somewhat different. In particular, airway design east of Chicago will depend upon a wide range of factors associated with traffic flow in the Golden Triangle. Also, the transition design east out of Chicago should be compatible with the transition routes west out of New York; otherwise an undesirable crossing traffic situation in the enroute area will result. Such considerations are beyond the scope of these guidelines, however.

9.3 CALIFORNIA CORRIDOR ENROUTE/TRANSITION DESIGN CONCEPT (Figure 38)

The airspace between the Los Angeles and San Francisco terminal areas is a distinctive example of how specially designed enroute airways are the most effective means to simultaneously accommodate both enroute and transition functions. This results from the relatively short distance between terminal areas, the number of airport pairs exchanging traffic in near common airspace, and the extremely high level of traffic exchanged by these airport pairs. Also, the amount of crossing traffic in the high-altitude airspace is light; therefore, more flexibility is available with respect to enroute altitude assignment.

In the design concept shown on Figure 38, two pairs of single direction airways are provided to accommodate the major traffic flow between the terminal areas with minimum potential for traffic conflicts. Bidirectional airways are established on each side of these pairs for over traffic proceeding north and south of the two major terminals. These airways are also connected to the San Francisco and Los Angeles terminals by transition segments for additional capacity and/or flexibility. For example, during peak LAX-SFO traffic, it may be advantageous to use these outside airways for other traffic, such as LAX-OAK, etc. Also, traffic may be distributed differently over the network as a result of wind conditions at the two terminals.

It should be noted that the design concept shown on Figure 38 is closely allied with the route structures within each terminal area and with the low-altitude airway structure between these terminals. This area, therefore, exemplifies the need for an integrated approach of terminal, high-altitude, and low-altitude route design.

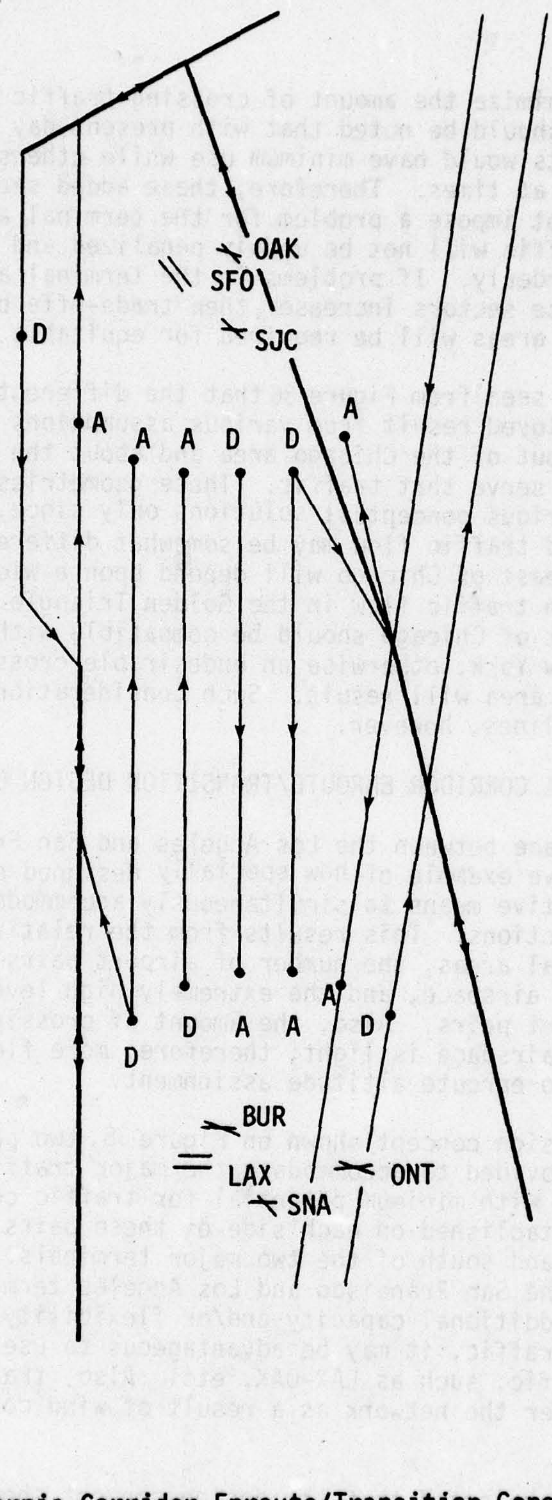


Figure 38 California Corridor Enroute/Transition Concept

9.4 NEW YORK TRANSITION DESIGN CONCEPT (Figure 39)

Upon examination of the charted high-altitude jet routes in the Northeastern U.S., together with the normal traffic flow on these routes, it is clear that the present route system in the Northeast has been basically tailored to ease the terminal and transition problems associated with New York traffic. In view of the complexities of the problems it can be expected that similar tailoring will be required for an effective RNAV route structure in this area. Without care, however, this approach can result in undesirable impact on other parts of the system and on the system users. Unless consideration is extended to traffic flows well beyond the New York area, excessive congestion in the enroute area can result as well as complex transition traffic flows in other terminals such as Cleveland, Pittsburgh, etc. Also, solutions to the New York terminal/transition problems, if developed independently, can cause excessive route miles and undesirable altitude assignments and/or restrictions. Further, with the heavy traffic flows in the Northeast, route-mileage increases quickly accumulate to substantial flight-mileage increases and these, together with undesirable altitudes, result in severe fuel consumption and other user penalties. Accordingly, it seems clear that development of the New York transition routes should be an integral part of a larger network design activity. If the route structure development cannot encompass the Golden Triangle area, as was considered necessary in the Reference 2 study, then traffic flows in this area should be established as the common denominator among the various design activities. Also, close coordination and feedback is necessary so that a solution to a problem in one area does not have an adverse impact on other areas. Trade-offs will be required so that an orderly traffic flow can be established throughout the area while also maintaining an equitable distribution of any necessary increases in flight-miles.

Obviously, consideration of all relevant factors for an effective New York transition design is beyond the scope and purpose of this guideline section. Therefore, the design shown on Figure 39 is only presented as one conceptual solution for the New York transition traffic which was developed without the necessary consideration of other traffic flows. For this design concept it was assumed that at least eight bidirectional enroute airways would be established to accommodate the east-west traffic flows. On the eastern end, these airways are divided into single-direction segments for climb and descent to and from enroute altitude. The heaviest flows are in the west and northwest terminal area sectors. In these sectors, three arrival and three departure waypoints are provided so that traffic to and from the major airports can be separated at and beyond the terminal perimeter, if desired. This approach may impose a slight mileage penalty, but that penalty would probably be offset by reduced restrictions in the climb and descent routings. In the northeast-southwest direction, it was assumed that high-altitude airways aligned with the Northeast Corridor traffic (Boston to Washington area) would be single direction, at least as far south as Washington. The assumption stems from a preliminary low-altitude RNAV study of the Northeast Corridor, where it was found that a common set of single-direction airways for both high- and low- altitude traffic seemed to offer the best solution. The heaviest low-altitude flows are from Washington to New York and from New York to Boston and other New England airports. Therefore, the airways crossing the

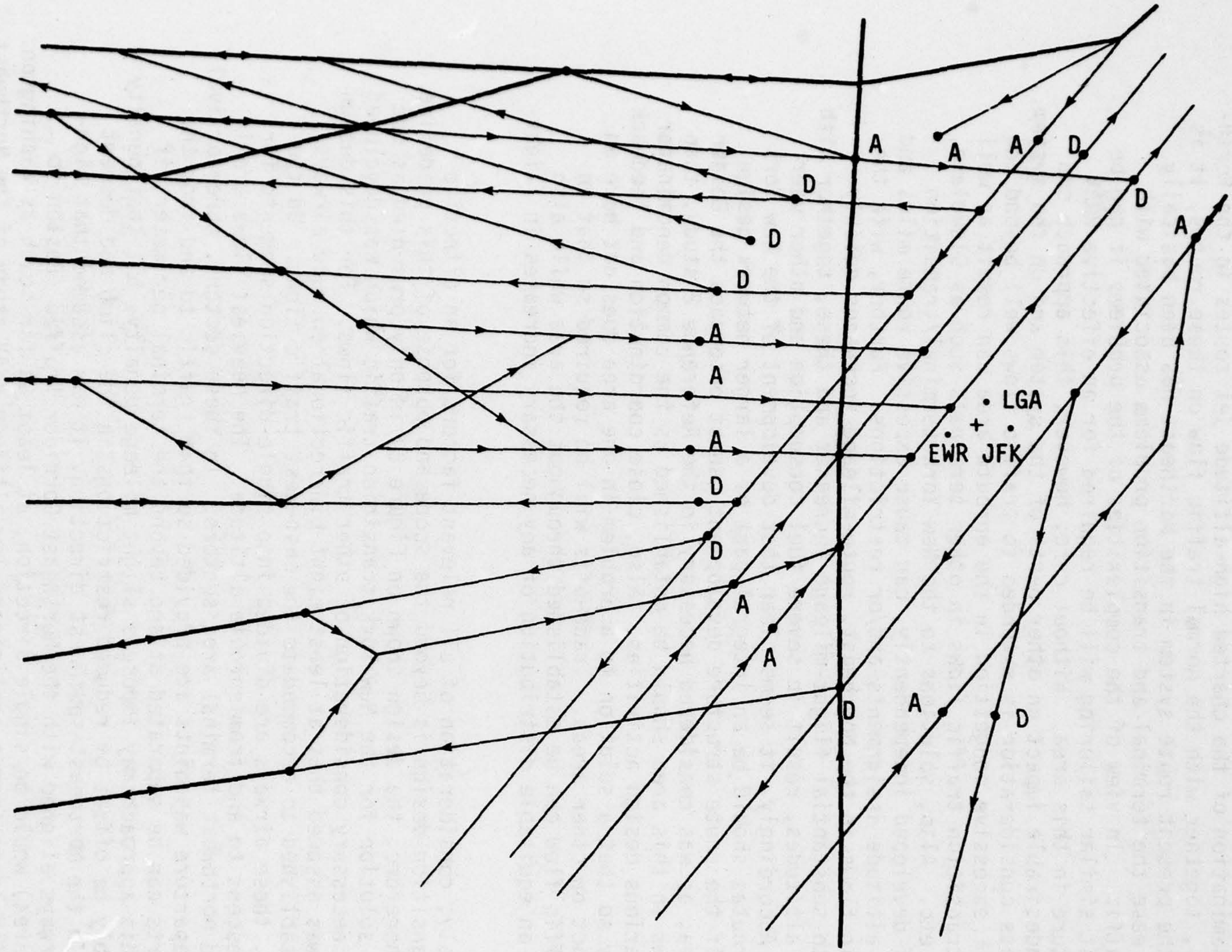


Figure 39 New York Transition Design Concept

New York terminal would probably be used by high-altitude traffic only. Routings and procedures for low-altitude traffic to and from the New England states is an age-old problem that requires separate study.

As stated, the transition route concepts shown on Figure 39 are predicated on certain assumptions about the enroute environment and about the New York terminal area requirements. It is obvious that with different assumptions these geometries would not apply. For example, it may turn out the most effective enroute structure would consist of single-direction airways for the total distance between New York and Chicago. Such an approach would result in an enroute/transition network of an entirely different form. Also, changes to the arrival/departure waypoint configuration on the terminal perimeter may cause substantial changes to transition route configurations. In any event it can be seen from Figure 39 that, although most of the transition design concepts and considerations discussed previously have been applied, special tailoring of the New York area is required to ensure manageable traffic flow without imposing undue penalty on the user.

10.0 TRANSITION DESIGN SUMMARY

The degree to which RNAV will provide benefits to the ATC system and to its users is largely dependent upon the design principles embodied in the enroute and terminal route structures. In particular, effective RNAV transition routing to and from assigned enroute altitude is a key element for overall system efficiency. To provide the most effective transition route design it is necessary that careful consideration be given to a wide range of factors. From previous RNAV studies the following factors appear the most essential:

1. Terminal Entry/Exit Waypoints - Compatibility between the terminal and transition phases of operation is achieved primarily through the configuration of the arrival and departure waypoints on the terminal perimeter. Normally, an initial configuration is developed by terminal route design and analysis with subsequent modifications to satisfy transition area requirements. However, regardless of the approach followed, the required compatibility can only result through close and continuous coordination between the activities involved in terminal and transition route design work.

2. One-Way Routes for Transition - Wherever possible, provision should be made for one-way traffic flows during the climb/descent phase of operations. This may be accomplished by:

a. Single-direction airway segments in the charted enroute structure or
b. Charted alternate airway segments specifically for climb and descent, or
c. Uncharted segments to be flown as a parallel offset from charted segments, or
d. Special transition routes associated with published SIDs and STARs.

3. Transition Route Length - The distance required for transition depends upon aircraft performance, assigned enroute altitude, altitude at the terminal entry/exit points, and ATC considerations. Due to variations in these factors, trade-offs are required for effective design. Normally, transition routes should be designed to accommodate predominant conditions. Less frequent events would then be handled as a normal function of ATC. Also, reduced transition route lengths may be required due to the undesirable impact of longer routes on the enroute structure or on other transition routes. In this case, traffic interactions which occur during the remainder of the transition phase can normally be resolved through use of the RNAV offset feature.

4. Number of Transition Segments - The number of segments on transition routes have an influence on avionics design, pilot workload, navigation accuracy, chart and video map clutter, and storage requirements in NAS computers. It naturally follows that the number of segments should be kept to a minimum, preferably three or less per transition route.

5. Intersection Geometry - Wherever possible the centerline spacing of adjacent transition segments should be sufficient for procedural separation between aircraft operating on the segments. When intersections are required, care should be given to the location of the intersection and to the angle. Between climb and descent segments the intersection should be located where altitude separation would normally exist based on nominal climb/descent gradients. If this is not possible the intersection angle should be as close to 45° as possible so as to minimize the elapsed time of altitude restrictions that may

be required. For other intersections and merge/demerge points, an angle of 10° or more should be maintained.

6. Use of Offset in Lieu of Charted Routes - Where the transition route is to be flown as an offset from a charted route, special consideration should be given to VORTAC coverage at the expected offset distances. Signal gaps may occur on offsets which are on the side opposite the VORTAC. If such gaps are covered by VORTACs not supporting the parent route, then the transition route should be based on these VORTACs rather than as on uncharted offset.

It seems apparent from the discussions in this guideline document that procedures for the design of transition routes cannot be set down in a step-by-step fashion as is done in Section 4.0 for the terminal area. There are several reasons for this. First, it must be assumed that the design of transition routes would be closely integrated with the development of the overall enroute and terminal area structures. Therefore, any attempt to isolate procedures for transition route design without taking into account the rest of the enroute and terminal area requirements would, at best, be an oversiplification of the problem. Secondly, it has been shown that the design of routes in the enroute/transition areas is a highly judgmental process. Design approaches so derived envolve from the imagination, operational experience, and analytical know-how of the network designer and therefore, cannot be reduced to straightforward design steps. A third reason for lack of finite procedural definition is the wide variation from area to area by which the various design concepts should be applied. A series of steps that may work for Chicago, for example, may lead to an unworkable solution at New York or other complex areas. In lieu of such procedures, therefore, the discussion in Section 9 has been provided which presents various applications of transition route design concepts at a few of the more complex terminal areas.

REFERENCES

1. E.D. McConkey, "Terminal Area Design-Analysis and Validation of RNAV Task Force Concepts", FAA-RD-76-194, prepared by Systems Control, Inc. (Vt), West Palm Beach, Florida for the Systems Research and Development Service of the Federal Aviation Administration, October 1976.

2. A.G. Halverson, et al, "Area Navigation High Altitude Network Study", Report No. FAA-RD-76-6, National Aviation Facilities Experimental Center of the Federal Aviation Administration, Atlantic City, New Jersey, February 1976.

3. R.J. Adams, "Area Navigation Procedures and Avionics Functional Capabilities", Final Report, prepared by Systems Control, Inc. (Vt), West Palm Beach, Florida for the Systems Research and Development Service of the Federal Aviation Administration, July 1976.

APPENDIX A

COMPUTER PROGRAM DESCRIPTIONS

A.1 INTRODUCTION

Seven of the computer programs that were used in the terminal design procedure are described in this appendix. The programs are written in Fortran Extended Version 4 for the Network Operating System (NOS) of the Control Data Corporation's (CDC) Cybernet Service. The specific characteristics of this Fortran language can be found in CDC Publication Number 60305600, "Control Data Cyber 70 Computer Systems - Models 72, 73, 74, 76 - 7600 Computer System - 6000 Computer Systems, Fortran Extended Version 4, Reference Manual", Control Data Corporation, Software Documentation, 215 Moffett Park Drive, Sunnyvale, California 94086.

The nominal input and output assignments for these programs are data files on the Cybernet System. In this system the files called TAPE1, TAPE2, ---, TAPEn, --- etc, are associated with the corresponding data set reference number contained in the specified READ or WRITE statement. Thus the input file for the statement READ (8,100) is found on TAPE8, etc. In a few of the programs, data and program control were input directly from the terminal keyboard. Input and output from the terminal is accomplished by using the instructions READ *format*, *iolist* or PRINT *format*, *iolist*. Thus an example of an instruction that requests input from the keyboard is READ 101, A,B,C. In some cases the format number is replaced by an asterisk. In these instances the input or output data is free form in nature, that is, the data elements are denoted by separators such as blanks, commas, etc.

One other system characteristic that should be considered is the word length of the CDC machine. The basic Fortran word contains 60 bits. This produces either 10 Hollerith characters or 20 octal digits of data. For conversion to 32 bit or 36 bit machines, the only programs which may require double precision computation is the LLRAB subroutine in the TEVALP program. This program converts latitude and longitude data to range and bearing information between waypoints. The use of single precision accuracy on 32 or 36 bit machines may produce slightly different results than were obtained with the 60 bit CDC computer. The alphanumeric data that is contained in these programs would need to be made compatible with the reduced word length machines. This would necessitate changing some input, output and DATA statements and redefinition of any array dimensions which were used to store alphanumeric data.

The remaining characteristics of Fortran Extended Version 4 should be generally familiar to most Fortran 4 users.

A.2 PROGRAM ASMBL

A.2.1 Purpose of Program

Program ASMBL is used to assemble the terminal area waypoints into a route structure. Each waypoint in the paper design of the route structure is assigned a latitude, longitude, altitude range and an index number. The routes are created by assembling a set of index numbers for each route. A functional description of ASMBL is shown in Figure A.1. The structure of the program is relatively straightforward.

PROGRAM ASMBL

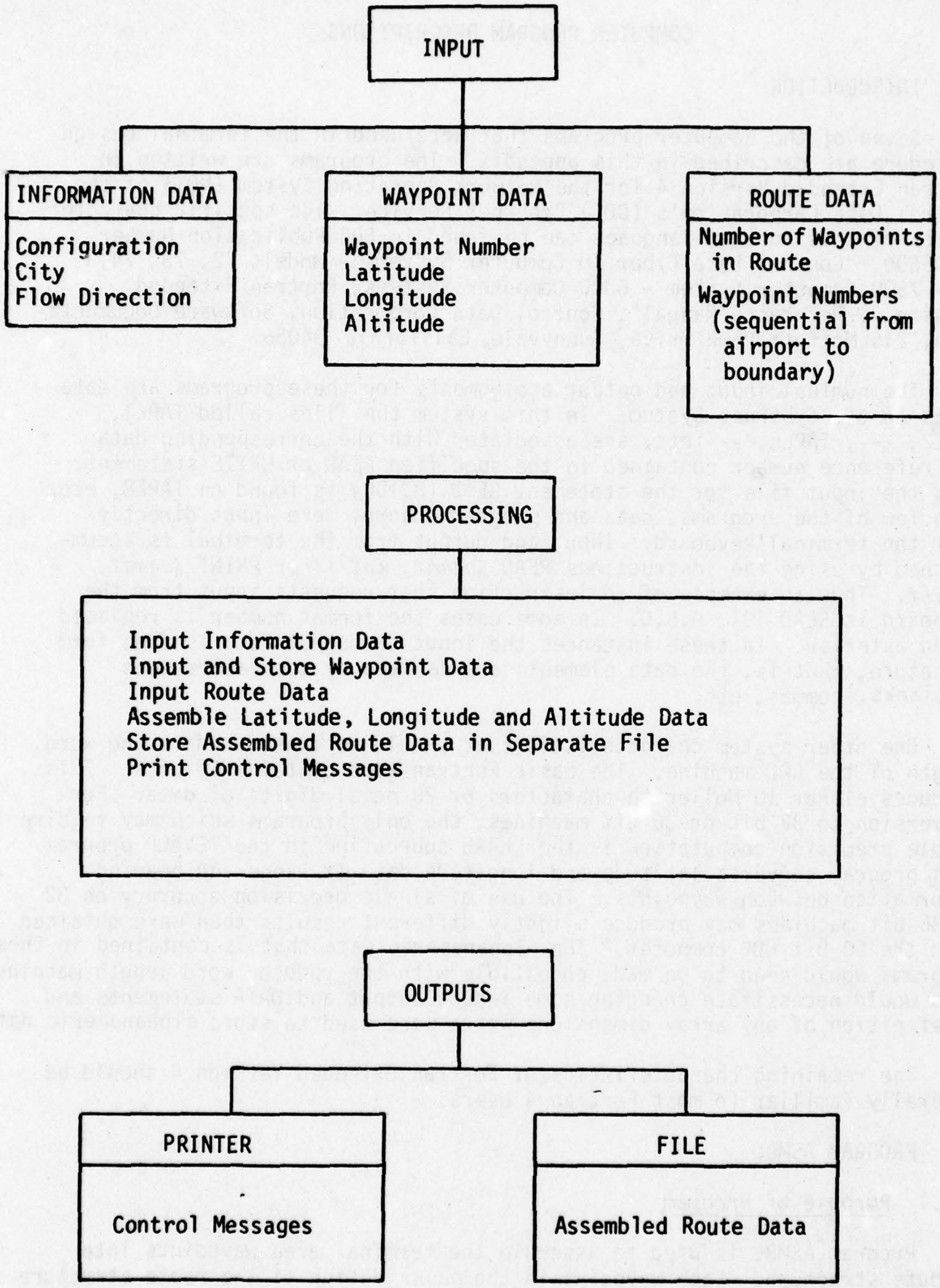


Figure A.1 ASMBL Program Functional Diagram

A.2.2 Input Data

The input data is contained in two files, TAPE7 and TAPE8. TAPE7 contains the waypoint data and TAPE8 contains the terminal information and route data. Each record in TAPE7 contains an index number, latitude, longitude and altitude. The format of each record is as follows:

Characters	Format	Description
1-6	6X	ignored
7-9	I3	index number
10-12	F3.0	latitude-degrees
13-17	F5.1	latitude-minutes (including fraction)
18-21	F4.0	longitude-degrees
22-26	F5.1	longitude-minutes (including fraction)
27-30	F4.0	altitude (hundreds of feet)
31	A1	+ or -
32-34	F3.0	altitude (can be blank)
35-39	—	ignored

The interpretation of the + or - in Column 31 is discussed in Section A.5 in the TMALST program. Characters 10-39 are read by ASMBL in a 3A10 format. However, if the above format is not followed, the TMALST program will not interpret the data properly.

The routes should be arranged in numerical order according to the following convention:

Route Numbers	Description
001-099	VOR-radar vector arrivals
101-199	VOR-radar vector departures
201-299	RNAV arrivals
301-399	RNAV departures

This convention is used in the TEVALP program to separate arrival and departure traffic in this program. An example of the data in the TAPE7 file is shown in Figure A.2.

The data in TAPE8 contain information about the routes. The records in TAPE8 must contain the following data:

Record	Description
1	configuration identification, description
2-N+1	route number, number of waypoints, waypoint index number

where N is the number of routes in the terminal route structure. For record 1, the data is arranged in the following format:

```
copy,tape7
00100 001 75 16.1  39 52.0   0
00110 002 75 23.0  39 50.5  20
00120 003 75 30.0  39 53.4  30
00130 004 75 31.2  39 56.9  40
00140 005 75 18.1  40 08.7  50
00150 006 75 06.5  40 19.0  60+
00160 007 75 09.4  40 37.5 100+
00170 008 74 39.6  40 28.4 100+
00180 009 75 27.4  39 46.0  30
00190 010 75 26.0  39 41.7  40
00200 011 75 10.8  39 43.5  60
00210 012 74 16.4  39 50.1 100+
00220 013 75 18.6  39 38.0  50
00230 014 75 12.8  39 36.5  60
00240 015 74 29.1  39 24.4 100+
00250 016 75 22.5  39 30.4  60
00260 017 75 32.5  39 10.6  90
00270 018 75 58.9  39 24.4 100+
00280 019 75 52.0  40 05.4  50
00290 020 76 09.0  40 08.2  60+
00300 021 75 13.5  39 52.7   0
00310 022 75 08.3  39 53.5  50-
00320 023 74 54.4  40 15.2  80+
00330 024 74 33.5  40 24.3 100+
00340 025 74 23.4  40 14.7 100+
00350 026 75 05.6  39 47.8  50
00360 027 74 57.9  39 32.3  50
00370 028 74 45.8  39 32.2  50
00380 029 74 22.5  39 32.0  60+
00390 030 74 55.4  39 27.6  50
00400 031 74 45.9  39 13.6  60+
00410 032 75 09.6  39 32.4  50
00420 033 75 11.9  39 24.6  60+
00430 034 75 36.0  39 11.0 100+
00440 035 75 09.4  39 53.5  30+
00450 036 75 25.2  39 56.6  50+
00460 037 75 40.5  39 55.1  60+
00470 038 76 10.0  39 40.2 100+
00480 039 76 12.4  39 54.6 100+
00490 040 76 12.0  39 58.1 100+
00500 041 75 18.4  40 04.0  60+
00510 042 75 34.0  40 13.6  80+
00520 043 75 52.4  40 26.5 100+
00530 044 75 39.0  40 33.8 100+
00540 045 75 06.6  39 53.9  20
00550 046 75 02.8  39 58.6  30
00560 047 75 04.0  40 02.0  40
00570 048 75 05.5  40 11.3  50
00580 049 74 25.9  39 49.0 100+
```

file line number

waypoint index number

latitude (degrees)

latitude (minutes)

longitude (degrees)

longitude (minutes)

altitude (hundreds of feet)

Figure A.2 Waypoint Input File for ASMBL

Characters	Format	Description
1-6	6X	ignored
7-14	A8	configuration identification
15-44	3A10	terminal description

The configuration identification in the Reference 1 study was written according to the following code:

year of design - airport number - serial number

Thus a number like 82-32-02 would mean a RNAV route structure designed for the year 1982 for airport number 32, the second route structure developed. This code may be modified as desired by the terminal designer. The terminal description can contain any alphanumeric data that would be helpful in describing the design. The first five characters should be the words bHIGH, bLOWb, or 5 blanks. This indicates whether the routes accommodate high-altitude or low-altitude traffic. The blanks assume high-altitude traffic is used. The remaining 25 characters contain the airport and the flow. Sixteen spaces are allowed for the airport followed by four characters for the flow. An example of the terminal description is the following:

82-32-01*HIGH*PHILADELPHIA****EAST

For records 2-N+1 the data is presented in a free format with the data separated by either blanks or commas. The data is arranged as follows:

Data Word	Name	Description
1	IGARB	ignored (file line number)
2	IROUT	route number
3	NPTS	number of waypoints in route
4,5,6,etc.	IWPS	waypoint index numbers (starting at airport and terminating at terminal boundary)

An example of the data in the TAPE8 file is presented in Figure A.3.

A.2.3 Output Data

The output of ASMBL is written on TAPE1. The first output record contains the configuration identification and description data. The remaining records contain the route structure data. Each record contains the following data:

file line number

design identification number

route number

number of waypoints in route

waypoint index numbers

```
copy,tape8
00100 82-32-07
00110 201 7 1 2 75 76 157 158 119
00120 202 7 1 2 75 76 157 158 120
00130 203 7 1 2 82 83 84 85 86
00140 204 7 1 2 82 83 84 85 87
00150 205 7 1 2 82 83 88 89 90
00160 206 7 1 2 82 83 88 89 91
00170 207 4 1 2 92 93
00180 208 4 1 2 92 94
00190 209 6 1 2 75 76 95 96
00200 210 6 1 2 75 76 95 97
00210 301 5 21 98 159 162 100
00220 302 3 21 98 101
00230 303 3 21 98 102
00240 304 4 21 98 103 104
00250 305 4 21 98 105 106
00260 306 5 21 98 105 107 108
00270 307 5 21 98 105 109 110
00280 308 6 21 98 159 160 163 113
00290 309 6 21 98 159 160 163 114
00300 310 5 21 98 159 161 115
 END OF INFORMATION ENCOUNTERED.
/
```

Figure A.3 Route Input File for ASMBL

Characters	Format	Description
1-3	I3	route number
4-6	3X	blank
7-9	F3.0	latitude-degrees
10-14	F5.1	latitude-minutes (including fraction)
15-18	F4.0	longitude-degrees
19-23	F5.1	longitude-minutes (including fraction)
24-27	F4.0	altitude (hundreds of feet)
28	A1	+ or -
29-31	F3.0	altitude (can be blank)
32-36	--	blank

The data for each route is presented sequentially starting at the airport and finishing at the terminal boundary. This is true regardless of whether the route is an arrival or a departure. An example of the output contained in TAPE1 is contained in Figure A. 4.

A.2.4 Program Description

The processing in ASMBL is generally straightforward. A detailed flow diagram of the program is shown in Figure A. 5. Initially, the configuration identification and description are read from TAPE8 and rewritten on output file TAPE1. The waypoint data are then read from TAPE 7 and stored in array LTD. The capacity of LTD is 400 waypoints. When an end of file on TAPE7 is reached, or when the 400 waypoint capacity of LTD is reached, input from TAPE7 ceases and the processing jumps to statement number 20. At this point the route information from TAPE8 is input one record at a time. The waypoint index numbers of the route are matched with the waypoint data in array LTD and the waypoint data are written sequentially on TAPE1 for all waypoints in the route. Then a new route is input from TAPE8. Processing continues until an end of file is detected in TAPE8. A message is printed on the terminal device stating that the processing is complete. Files TAPE1, TAPE7 and TAPE8 are returned to their start position and the program execution halts on a STOP instruction.

A.2.5 Program Listing and Examples

A listing of program ASMBL is presented in Figure A.6.

A.3 PROGRAM TMALST

A.3.1 Purpose of Program

Program TMALST reformats the route data provided by ASMBL and displays the route segment distances, bearings, permissible altitude ranges and vertical path angles for each route segment. The output of TMALST permits easy comparison of the route structure with maps to provide rapid error identification and correction. The TMALST program produces an output file of route structures which is used by the TEVALP program. A functional description of the TMALST program is shown in Figure A.7.

```
copy,tape1
82-32-07
201       75 16.1   39 52.0    0
201       75 23.0   39 50.5   20
201       75 30.0   39 54.0   30
201       75 31.2   39 57.8   40
201       75 05.3   40 10.2   50
201       74 56.5   40 14.4   60+
201       74 51.4   40 33.8   80+
202       75 16.1   39 52.0    0
202       75 23.0   39 50.5   20
202       75 30.0   39 54.0   30
202       75 31.2   39 57.8   40
202       75 05.3   40 10.2   50
202       74 56.5   40 14.4   60+
202       74 38.9   40 28.0   80+
203       75 16.1   39 52.0    0
203       75 23.0   39 50.5   20
203       75 27.5   39 45.8   30
203       75 26.5   39 41.6   40
203       75 09.0   39 44.8   60
203       74 42.0   39 50.7  100+
203       74 17.0   39 55.9  100+
204       75 16.1   39 52.0    0
204       75 23.0   39 50.5   20
204       75 27.5   39 45.8   30
204       75 26.5   39 41.6   40
204       75 09.0   39 44.8   60
204       74 42.0   39 50.7  100+
204       74 18.0   39 43.9  100+
205       75 16.1   39 52.0    0
205       75 23.0   39 50.5   20
205       75 27.5   39 45.8   30
205       75 26.5   39 41.6   40
205       75 22.4   39 36.1   60
205       75 15.9   39 27.2   60
205       75 09.5   39 08.0   80+
206       75 16.1   39 52.0    0
206       75 23.0   39 50.5   20
206       75 27.5   39 45.8   30
206       75 26.5   39 41.6   40
206       75 22.4   39 36.1   60
206       75 15.9   39 27.2   60
206       75 25.9   39 08.9   80+
207       75 16.1   39 52.0    0
207       75 23.0   39 50.5   20
207       75 44.2   39 42.1   70
207       76 04.0   39 28.9  100+
```

design identification number

route number

latitude (degrees)

latitude (minutes)

longitude (degrees)

longitude (minutes)

altitude (hundreds of feet)

Figure A.4 TAPE1 Output File from ASMBL

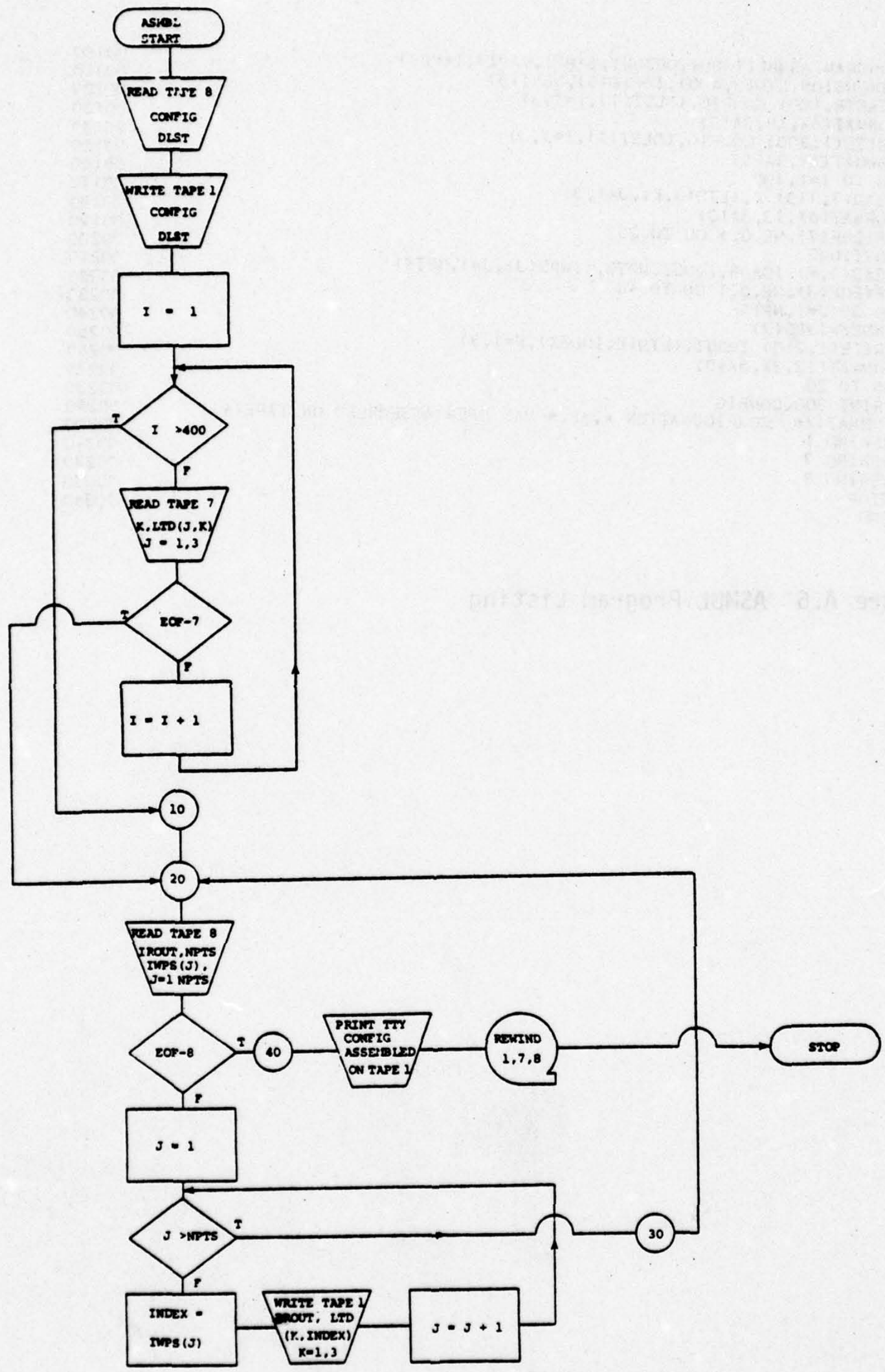


Figure A.5 ASMBL Program Flow Diagram

```
      PROGRAM ASMBL(INPUT,OUTPUT,TAPE1,TAPE7,TAPE8)
      DIMENSION LTD(3,400),INPS(15),DLST(3)
      READ(8,100) CONFIG,(DLST(I),I=1,3)
100   FORMAT(6X,A8,3A10)
      WRITE(1,200) CONFIG,(DLST(I),I=1,3)
200   FORMAT(A8,3A10)
      DO 10 I=1,400
      READ(7,110) K,(LTD(J,K),J=1,3)
110   FORMAT(6X,I3,3A10)
      IF(EOF(7).NE.0.) GO TO 20
10    CONTINUE
20    READ(8,*) IGARB,IROUT,NPTS,(INPS(J),J=1,NPTS)
      IF(EOF(8).NE.0.) GO TO 40
      DO 30 J=1,NPTS
      INDEX=INPS(J)
30    WRITE(1,210) IROUT,(LTD(K,INDEX),K=1,3)
210   FORMAT(I3,3X,3A10)
      GO TO 20
40    PRINT 300,CONFIG
300   FORMAT(/* CONFIGURATION *,A8,* HAS BEEN ASSEMBLED ON TAPE1*)
      REWIND 1
      REWIND 7
      REWIND 8
      STOP
      END
```

Figure A.6 ASMBL Program Listing

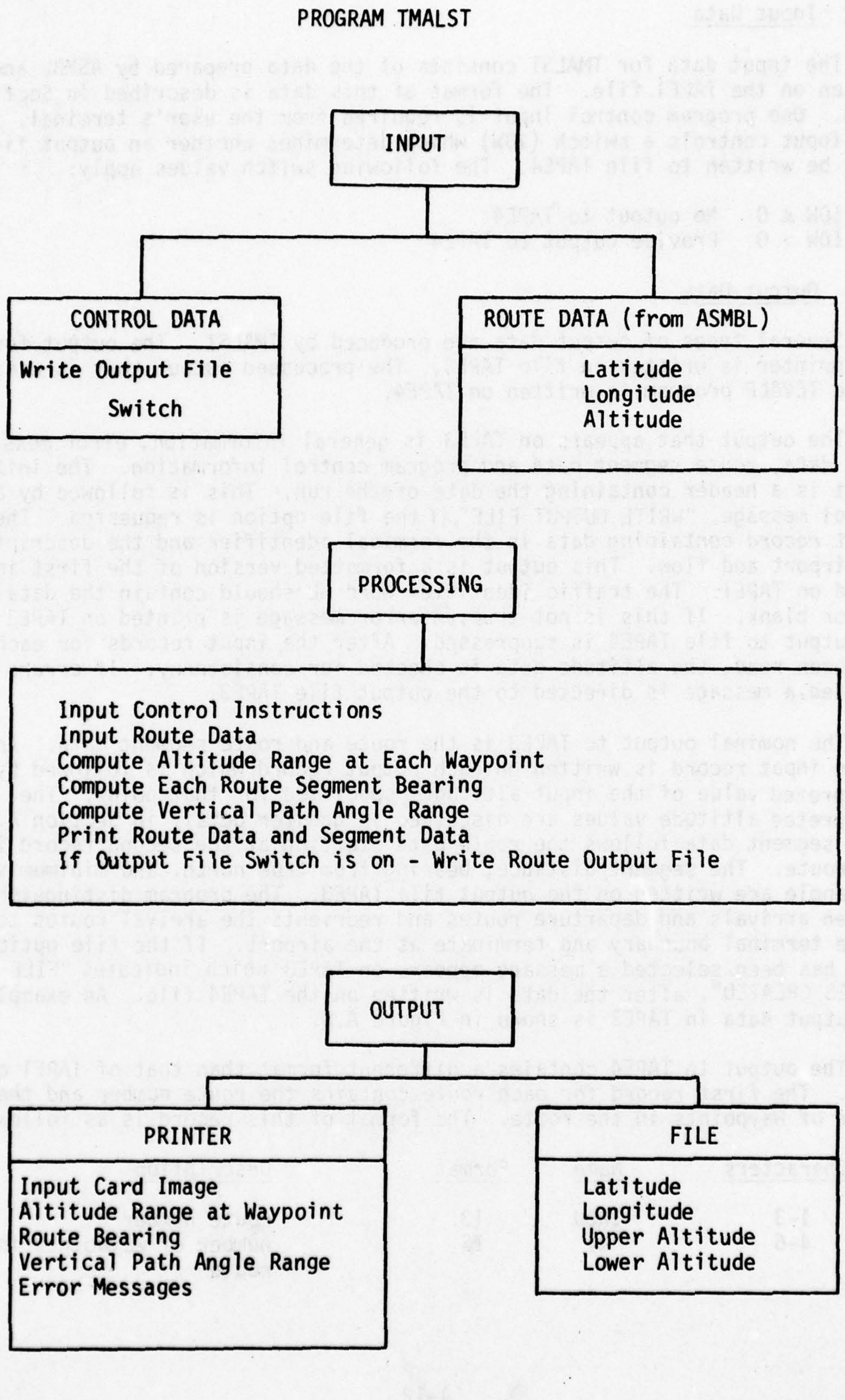


Figure A.7 TMALST Program Functional Diagram

A.3.2 Input Data

The input data for TMALST consists of the data prepared by ASMBL and written on the TAPE1 file. The format of this data is described in Section A.2.3. One program control input is required from the user's terminal. This input controls a switch (IDW) which determines whether an output file is to be written to file TAPE4. The following switch values apply:

IDW ≤ 0   No output to TAPE4
IDW > 0   Provide output to TAPE4

A.3.3 Output Data

Several types of output data are produced by TMALST. The output for the line printer is written on file TAPE3. The processed output that is used by the TEVALP program is written on TAPE4.

The output that appears on TAPE3 is general information, error messages, route data, route segment data and program control information. The initial output is a header containing the date of the run. This is followed by a program control message, "WRITE OUTPUT FILE",if the file option is requested. The next output record containing data is the terminal identifier and the description of the airport and flow. This output is a formatted version of the first input record on TAPE1. The traffic identifier word HL should contain the data HIGH, LOW, or blank. If this is not true,an error message is printed on TAPE3 and the output to file TAPE4 is suppressed. After the input records for each route have been read, the altitude data is checked for consistency. If errors are detected,a message is directed to the output file TAPE3.

The nominal output to TAPE3 is the route and route segment data. An image of the input record is written on each output record which is followed by the interpreted value of the input altitudes specified for that point. The interpreted altitude values are discussed in greater detail in Section A.3.4. Route segment data follows the route data starting at the second record in each route. The segment distance, bearing from true north, and minimum vertical path angle are written on the output file TAPE3. The program distinguishes between arrivals and departure routes and reorients the arrival routes to begin at the terminal boundary and terminate at the airport. If the file option for TAPE4 has been selected a message appears on TAPE3 which indicates "FILE ENTRIES CREATED", after the data is written on the TAPE4 file. An example of the output data in TAPE3 is shown in Figure A.8.

The output to TAPE4 contains a different format than that of TAPE1 or TAPE3. The first record for each route contains the route number and the number of waypoints in the route. The format of this record is as follows:

Characters	Name	Format	Description
1-3	IROU	I3	route number
4-6	NI	I3	number of waypoints in the route

copy,tape3

TMA DESIGN DATA LIST 77/12/21.

WRITE OUTPUT FILE

CONFIGURATION	AIRPORT	FLOW
82-32- 7		77/12/21.

201	74	51.4	40	33.8	80+	8000.	99900.			
201	74	56.5	40	14.4	60+	6000.	99900.	7.2	44.6	-2.6
201	75	05.3	40	10.2	50	5000.	5000.	8.9	7.0	-1.1
201	75	31.2	39	57.8	40	4000.	4000.	26.1	6.8	-.4
201	75	30.0	39	54.0	30	3000.	3000.	1.5	141.6	-6.1
201	75	23.0	39	50.5	20	2000.	2000.	7.1	172.8	-1.3
201	75	16.1	39	52.0	0	0.	0.	6.9	183.2	-2.7
202	74	38.9	40	28.0	80+	8000.	99900.			
202	74	56.5	40	14.4	60+	6000.	99900.	18.0	11.3	-1.1
202	75	05.3	40	10.2	50	5000.	5000.	8.9	7.0	-1.1
202	75	31.2	39	57.8	40	4000.	4000.	26.1	6.8	-.4
202	75	30.0	39	54.0	30	3000.	3000.	1.5	141.6	-6.1
202	75	23.0	39	50.5	20	2000.	2000.	7.1	172.8	-1.3
202	75	16.1	39	52.0	0	0.	0.	6.9	183.2	-2.7
203	74	17.0	39	55.9	100+	10000.	99900.			
203	74	42.0	39	50.7	100+	10000.	99900.	25.0	3.1	0.0
203	75	09.0	39	44.8	60	6000.	6000.	27.0	3.2	-1.4
203	75	26.5	39	41.6	40	4000.	4000.	17.5	2.6	-1.1
203	75	27.5	39	45.8	30	3000.	3000.	1.5	313.5	-6.5
203	75	23.0	39	50.5	20	2000.	2000.	4.7	194.8	-2.0
203	75	16.1	39	52.0	0	0.	0.	6.9	183.2	-2.7
204	74	18.0	39	43.9	100+	10000.	99900.			
204	74	42.0	39	50.7	100+	10000.	99900.	24.1	355.7	0.0
204	75	09.0	39	44.8	60	6000.	6000.	27.0	3.2	-1.4
204	75	26.5	39	41.6	40	4000.	4000.	17.5	2.6	-1.1
204	75	27.5	39	45.8	30	3000.	3000.	1.5	313.5	-6.5
204	75	23.0	39	50.5	20	2000.	2000.	4.7	194.8	-2.0
204	75	16.1	39	52.0	0	0.	0.	6.9	183.2	-2.7
205	75	09.5	39	08.0	80+	8000.	99900.			
205	75	15.9	39	27.2	60	6000.	6000.	8.1	322.7	-2.3
205	75	22.4	39	36.1	60	6000.	6000.	6.9	340.9	0.0
205	75	26.5	39	41.6	40	4000.	4000.	4.3	341.4	-4.3
205	75	27.5	39	45.8	30	3000.	3000.	1.5	313.5	-6.5
205	75	23.0	39	50.5	20	2000.	2000.	4.7	194.8	-2.0
205	75	16.1	39	52.0	0	0.	0.	6.9	183.2	-2.7

Repeat of input data

route number

latitude

longitude

altitude

minimum altitude

maximum altitude

route segment distance

route segment bearing

vertical path angle

*An altitude of 99900. indicates unrestricted design altitude.

Figure A.8 Route Data Output from TMALST

The next NI records contain the waypoint data. The format of these records is as follows:

Characters	Format	Description
1-10	F10.5	latitude (fractional degrees)
11-20	F10.5	longitude (fractional degrees)
21-23	I3	minimum altitude (hundreds of feet)
24-26	I3	maximum altitude (hundreds of feet)

The following record contains the next route number and the number of waypoints in that route. The next records are the waypoints for the second route. This pattern continues for all arrival and departure routes in the specified terminal area configuration.

The data contained in TAPE4 is used as an input to the TEVALP program. The data in TAPE3 is used to compare the data in storage with map data in order to correct any erroneous data. An example output from the TAPE4 file is presented in Figure A.9.

A.3.4 Program Description

A detailed flow diagram of TMALST is shown in Figure A.10. The processing from the beginning of the program to statement number 7 sets constants, writes the date on unit 3 and reads the output file switch value from the user's terminal. From 7 to 19, the first data record is read from unit 1 and checked for the proper format and indicator value. At 19 flags and counters are initialized. The section from 20 to 22 is used to read the first waypoint data record in each design configuration. After this card is read, ISKIP is set to 1 and this section is bypassed. At 22 the route number is decoded and saved in IRFST, IRTYP, IRNAV and IARDP. The flags have the following values:

IRTYP	- 0	VOR arrivals
	- 1	VOR departures
	- 2	RNAV arrivals
	- 3	RNAV departures
IRNAV	- 1	VOR routes
	- 2	RNAV routes
IARDP	- 1	arrivals
	- 2	departures

At 21, the program branches to 35 if the route number in DATA(1) and IRFST are not identical. This occurs when the first card in the next route is read. Processing from 21 to 24 is concerned with storing the route data in the RLST and JMAGE arrays.

Processing from 24 to 33 involves the interpretation of the waypoint altitudes. The altitude data can have one of the four following forms:

```
/copy,tape4
82-32- 7
201   7
   75.26333   39.36667  0  0
   75.33333   39.34167 20 20
   75.50000   39.90000 30 30
   75.52000   39.96333 40 40
   75.03333   40.17000 50 50
   74.94167   40.24000 60999
   74.85667   40.56333 80999
202   7
   75.26333   39.86667  0  0
   75.33333   39.84167 20 20
   75.50000   39.90000 30 30
   75.52000   39.96333 40 40
   75.03333   40.17000 50 50
   74.94167   40.24000 60999
   74.64833   40.46667 80999
203   7
   75.26833   39.36667  0  0
   75.33333   39.34167 20 20
   75.45333   39.76333 30 30
   75.44167   39.69333 40 40
   75.15000   39.74667 60 60
   74.70000   39.845001 00999
   74.28333   39.931671 00999
204   7
   75.26833   39.86667  0  0
   75.33333   39.84167 20 20
   75.45333   39.76333 30 30
   75.44167   39.69333 40 40
   75.15000   39.74667 60 60
   74.70000   39.845001 00999
   74.30000   39.731671 00999
205   7
   75.26333   39.86667  0  0
   75.33333   39.84167 20 20
   75.45833   39.76333 30 30
       1167   39.69333 10 40
         33   39.60167 60 60
          0   39.45333 60 60
   75.15333   39.13333 80999
206   7
   75.26333   39.86667  0  0
   75.33333   39.84167 20 20
   75.45333   39.76333 30 30
   75.44167   39.69333 40 40
   75.37333   39.60167 60 60
   75.26500   39.45333 60 60
   75.43167   39.14333 80999
```

route number, number of waypoints

latitude (degrees)

longitude (degrees)

minimum altitude (hundreds of feet)

maximum altitude (hundreds of feet)

Figure A.9 TAPE4 Output File from TMALST

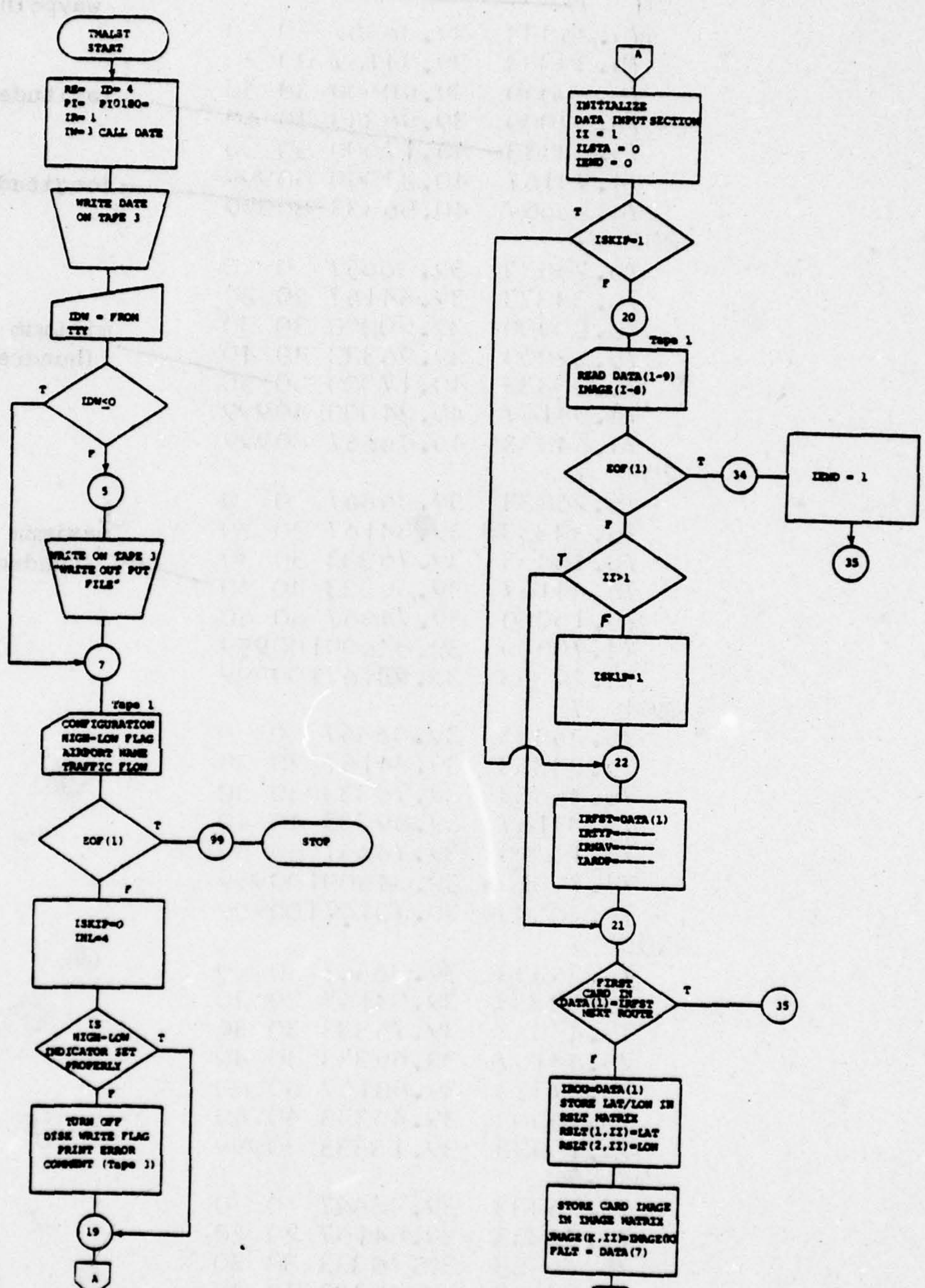


Figure A.10 TMALST Program Flow Diagram (Pg. 1 of 3)

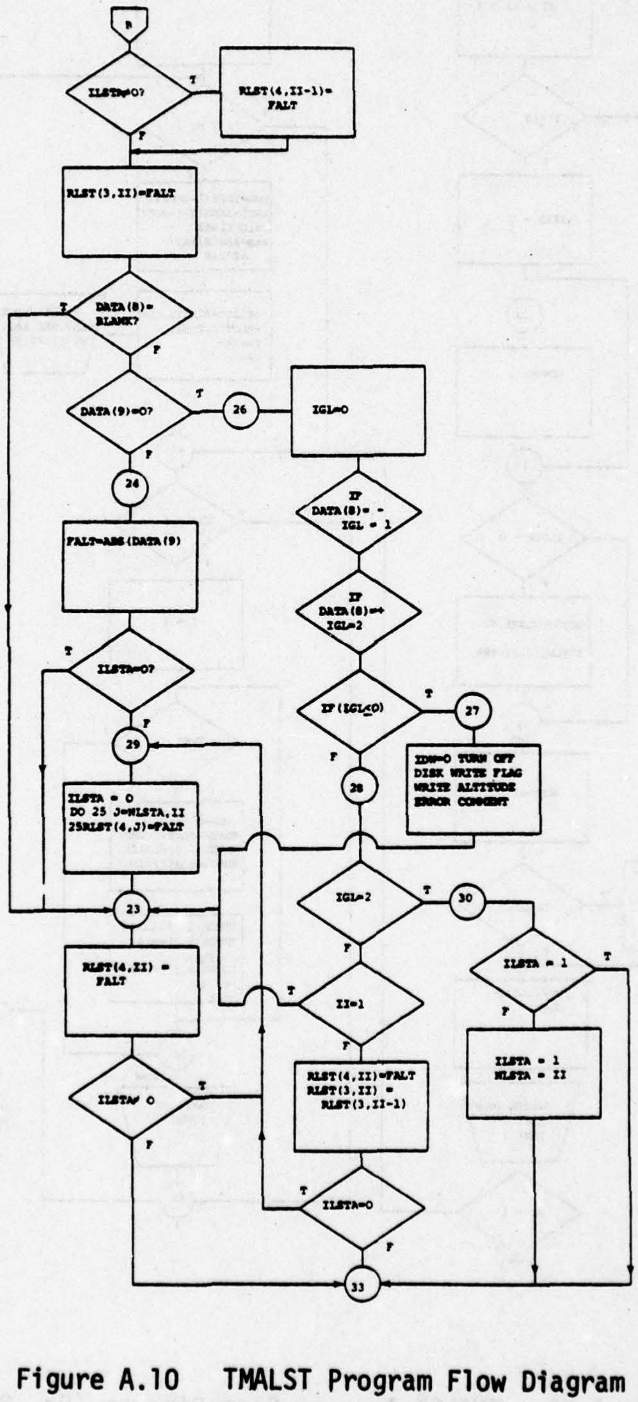


Figure A.10 TMALST Program Flow Diagram (Pg. 2 of 3)

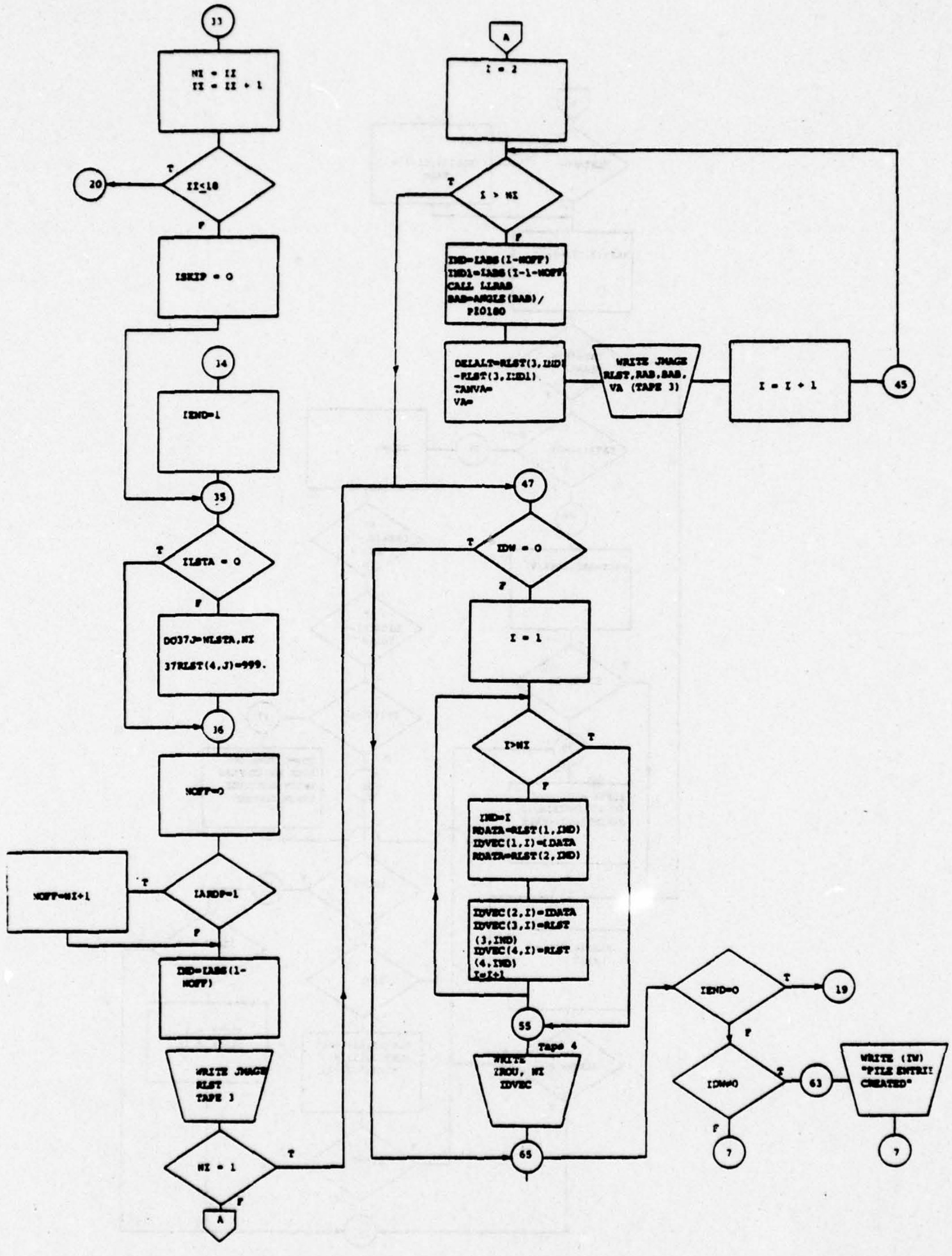


Figure A.10 TMALST Program Flow Diagram (Pg. 3 of 3)

Case	DATA(7)	DATA(8)	DATA(9)
1	Altitude 1	Blank	blank
2	Altitude 1	+	blank
3	Altitude 1	-	blank
4	Altitude 1	-	altitude 2

Case 1 is interpreted as a single fixed altitude at the waypoint. Case 2 means that the aircraft must be at least at altitude 1 at the waypoint but it can be above altitude 1. If there is a maximum altitude restriction at some later point, then the maximum altitude at this waypoint will be set to that maximum value. For example, if waypoint 3 shows 80 + (hundreds of feet) and waypoint 4 shows a fixed altitude of 120, then the maximum altitude at waypoint 3 is set to 120. If, on the other hand, all later waypoints have no restrictions, then the upper altitude restriction at the waypoint is set at 999 (99900 ft) to indicate no restrictions. Case 3 is similar to Case 2 except that the lower altitude bound is set by some previous altitude. For example, if waypoint 2 has an altitude of 20 (2000 ft.) and waypoint 3 has an altitude of 50-, then the permissible altitudes at 3 are 20 to 50 (2000-5000 ft.). Case 4 is relatively straight forward since it produces a permissible altitude range. This does, however, give a dual interpretation to the "-" symbol. The purpose of the conditionals and jumps between statement numbers 24 to 33 is to decode these four cases and select the appropriate altitudes for the waypoint.

At 33 the waypoint counter II is saved in NI and II is advanced. If less than 18 waypoints are in storage, then the processing jumps back to location 20 to read another waypoint input record.

At 35, the remaining unrestricted altitude assignments are made if ILSTA is nonzero. At 36, the index for arrival routes is reversed by using the IARDP parameter to set NOFF. The first waypoint is written from the JMAGE and RLST arrays to unit 3. If only one waypoint is in the route (a result of erroneous input data), processing jumps to 47. Otherwise the range and bearing angle between waypoints are calculated using subprograms LLRAB and ANGLE. Subroutine LLRAB uses spherical earth computations to determine the range and bearing between the two input latitude and longitude values. Function ANGLE assures that the angular output is between 0° and 360°. The vertical path angle is computed from the two minimum altitude values at the waypoint. This variable is useful in finding gross altitude errors. The data from JMAGE, RLST, segment distance, segment bearing and vertical path angle are output to unit 3. This processing continues until all waypoints in the route have been exhausted. Processing then jumps to location 47.

The operations from 47 to 65 are skipped if the file output to unit 4 is not requested. Otherwise, the data in the RLST array is reformatted and placed in the IDVEC array. From there the data is output to unit 4. At 65, the parameter IEND is checked. A zero value indicates that no end of file has been detected and processing jumps to location 19 to process the next route. If an end of file is encountered IEND is set to 1 and processing jumps to location 7 whereupon another configuration can be processed. If an end of file

is detected at this point, program execution halts at location 99 with a STOP instruction.

A.2.5 Program Listing and Examples

A listing of TMALST is presented in Figure A.11.

A.4 PROGRAM TEVALP

A.4.1 Purpose of Program

The TEVALP program evaluates the terminal route structures in terms of user time, fuel and distance flown penalties. The program uses the routes created by ASMBL and TMALST and a traffic sample derived from TRPUN to perform this evaluation. Traffic weighted values of route length and misalignment distance are determined. Also, time and fuel penalties incurred by aircraft being held below their optimum climb or descent profiles are computed by the program. Finally, the program output is annotated so that route segments that produce user penalties or profile attainment problems can be quickly identified. A functional description of the TEVALP program is shown in Figure A.12. It is apparent that a considerable amount of aircraft data is required by the program. This data is derived from performance handbooks of the specific aircraft being considered. A detailed discussion of the aircraft data requirements is found in the next section.

A.4.2 Input Data

Data input for the TEVALP program comes from three files, TAPE4, TAPE5 and TAPE6. File TAPE4 contains route data from the TMALST program. The format and data content of that file are discussed in Section A.3.3.

The traffic sample data and some terminal data are contained in the TAPE5 file. The first record of this file contains the coordinates of the center of the terminal area and the radius of the conceptual terminal area circle. This record is composed of the following:

Characters	Name	Format	Description
1-5	—	5X	ignored
6-15	ALAD	F10.5	latitude (degrees including fraction)
16-25	ALOD	F10.5	longitude(degrees including fraction)
26-35	APRAD	F10.5	radius (nm)

The remaining records of TAPE5 contain the traffic demand data for the route structure being considered. This data contains two data words per record and is written in the free format form with the words separated by commas or blanks. The two data words are:

```
      PROGRAM TMALST(INPUT,OUTPUT,TAPE1,TAPE3,TAPE4)
C     PROGRAM TO LIST,ANNOTATE AND STORE TMA DESIGN DATA
      DIMENSION RLST(4,18),DATA(9),APNAM(4),RV(2),ARRDEP(3,2)
      DIMENSION HILO(4),IMAGE(8),IDVEC(4,18)
      DIMENSION ICFID(3),JMAGE(8,18)
C     RLST - LAT,LON,ALT1,ALT2
      EQUIVALENCE(RDATA,IDATA)
      COMMON RE,PI,IR,IW
      DATA RV/3HVOR,4HRNAV/,ARRDEP/4HARRI,4HVALS,1H ,4HDEPA,4HRTUR,2HES/
      DATA BL/1H /,PL/1H+/,AMIN/1H-/,HILO/1H ,4HHIGH,3HLOW,4H****/
      DATA STOP/4HSTOP/
      RE=3437.74677
      PI=3.141592654
      IR=1
      IW=3
      ID=4
      PIO180=PI/180.
      CALL DATE(HDATE)
C     WRITE HEADER
      WRITE(IW,201) HDATE
201   FORMAT(////T20,*TMA DESIGN DATA LIST*,2X,A10,/)
C     READ OPTIONS
      READ 101,IDW
101   FORMAT(I1)
      IF(IDW) 7,7,5
5     WRITE(IW,202)
202   FORMAT(T20,*WRITE OUTPUT FILE*/)
7     READ(IR,102) ICFID,HL,APNAM,FLO
      IF(EOF(IR).NE.0.) GO TO 99
      IF(IDW.NE.0) WRITE(ID,199) ICFID
199   FORMAT(I2,1H-,I2,1H-,I2)
102   FORMAT(3(I2,1X),A4,T15,5A4)
      ISKIP=0
      IHL=4
      DO 8 I=1,3
      IF(HL.EQ.HILO(I)) IHL=I
8     CONTINUE
      WRITE(IW,203) ICFID,HILO(IHL),APNAM,FLO,HDATE
203   FORMAT(T20,*CONFIGURATION*,T44,*AIRPORT*,T60,*FLOW*//T20,
     1I2,2(*-*,I2),1X,A4,T40,4A4,T60,A4,5X,A10//)
      IF(IHL.LT.4) GO TO 19
      IDW=0
      WRITE(IW,214) HL
214   FORMAT(T20,*ERROR - INVALID TYPE DESCRIPTOR *,*-*,A4,*-*///)
C     READ DATA FOR ONE ROUTE
19    II=1
      ILSTA=0
      IEND=0
      IF(ISKIP.EQ.1) GO TO 22
20    READ(IR,103) DATA,IMAGE
103   FORMAT(3F3.0,F5.1,F4.0,F5.1,F4.0,A1,F3.0,T1,8A4)
      IF(EOF(IR).NE.0.) GO TO 34
      IF(II.GT.1) GO TO 21
      ISKIP=1
22    IRFST=DATA(1)
      IRTYP=IRFST/100
      IRNAV=IRTYP/2+1
      IANDP=(IRTYP+1)/2-IRNAV+2
21    IF(DATA(1).NE.IRFST) GO TO 35
      IROU=DATA(1)
```

Figure A.11 TMALST Program Listing (Page 1 of 3)

```
      RLST(1,II)=DATA(3)+DATA(4)/60.
      RLST(2,II)=DATA(5)+DATA(6)/60.
      DO 3 K=1,8
3     JMAGE(K,II)=IMAGE(K)
      FALT=DATA(7)
      IF(ILSTA.NE.0) RLST(4,II-1)=FALT
      RLST(3,II)=FALT
      IF(DATA(8).EQ.BL) GO TO 23
      IF(DATA(9)) 24,26,24
24    FALT=ABS(DATA(9))
      IF(ILSTA.EQ.0) GO TO 23
29    ILSTA=0
      DO 25 J=NLSTA,II
25    RLST(4,J)=FALT
23    RLST(4,II)=FALT
      IF(ILSTA.NE.0) GO TO 29
      GO TO 33
C     IGL - 1=LESS,2=GREATER
26    IGL=0
      IF(DATA(8).EQ.AMIN) IGL=1
      IF(DATA(8).EQ.PL) IGL=2
      IF(IGL) 27,27,28
27    WRITE(IW,207)
207   FORMAT(T20,*ERROR - ALTITUDE*///)
      IDN=0
      GO TO 23
28    IF(IGL.EQ.2) GO TO 30
      IF(II.EQ.1) GO TO 23
      RLST(4,II)=FALT
      RLST(3,II)=RLST(3,II-1)
      IF(ILSTA.NE.0) GO TO 29
      GO TO 33
30    IF(ILSTA.EQ.1) GO TO 33
      ILSTA=1
      NLSTA=II
33    NI=II
      II=II+1
      IF(II.LE.18) GO TO 20
      ISKIP=0
      GO TO 35
34    IEND=1
C     LIST DATA
35    IF(ILSTA.EQ.0) GO TO 36
      DO 37 J=NLSTA,NI
37    RLST(4,J)=999.
C     TURN ARRIVALS AROUND
36    NOFF=0
      IF(IARDP.EQ.1) NOFF=NI+1
C     LIST POINTS
      IND=IABS(1-NOFF)
      WRITE(IW,208)
208   FORMAT(/)
      WRITE(IW,209) (JMAGE(I,IND),I=1,8),(RLST(I,IND),I=3,4)
209   FORMAT(T3,8A4,2(2PF8.0),0PF6.1,F7.1,F6.1)
      IF(NI.EQ.1) GO TO 47
      DO 45 I=2,NI
      IND=IABS(I-NOFF)
      IND1=IABS(I-1-NOFF)
      CALL LLRAB(RLST(1,IND1)*PIO180,-RLST(2,IND1)*PIO180,RLST(1,IND)*
     1PIO180,-RLST(2,IND)*PIO180,RAB,BAB)
```

Figure A.11 TMALST Program Listing (Page 2 of 3)

```
      BAB=ANGLE(BAB)/PIO180
      DELALT=RLST(3,IND)-RLST(3,IND1)
      TANVA=DELALT/60.76115/RAB
      VA=ATAN(TANVA)/PIO180
      WRITE(IW,209) (JMAGE(J,IND),J=1,8),(RLST(J,IND),J=3,4),RAB,BAB,VA
45    CONTINUE
C    MAKE FILE ENTRIES
47    IF(IDW.EQ.0) GO TO 65
      DO 55 I=1,NI
      IND=I
      RDATA=RLST(1,IND)
      IDVEC(1,I)=IDATA
      RDATA=RLST(2,IND)
      IDVEC(2,I)=IDATA
      IDVEC(3,I)=RLST(3,IND)
55    IDVEC(4,I)=RLST(4,IND)
      WRITE(ID,309) IROU,NI
      WRITE(ID,304) ((IDVEC(I,J),I=1,4),J=1,NI)
309   FORMAT(2I3)
304   FORMAT(2F10.5,2I3)
C    READ MORE ROUTES
65    IF(IEND.EQ.0) GO TO 19
      IF(IDW.NE.0) GO TO 63
      GO TO 7
63    WRITE(IW,215)
215   FORMAT(/T20,*FILE ENTRIES CREATED*////)
      GO TO 7
99    STOP
      END
```

Figure A.11 TMALST Program Listing (Page 3 of 3)

PROGRAM TEVALP

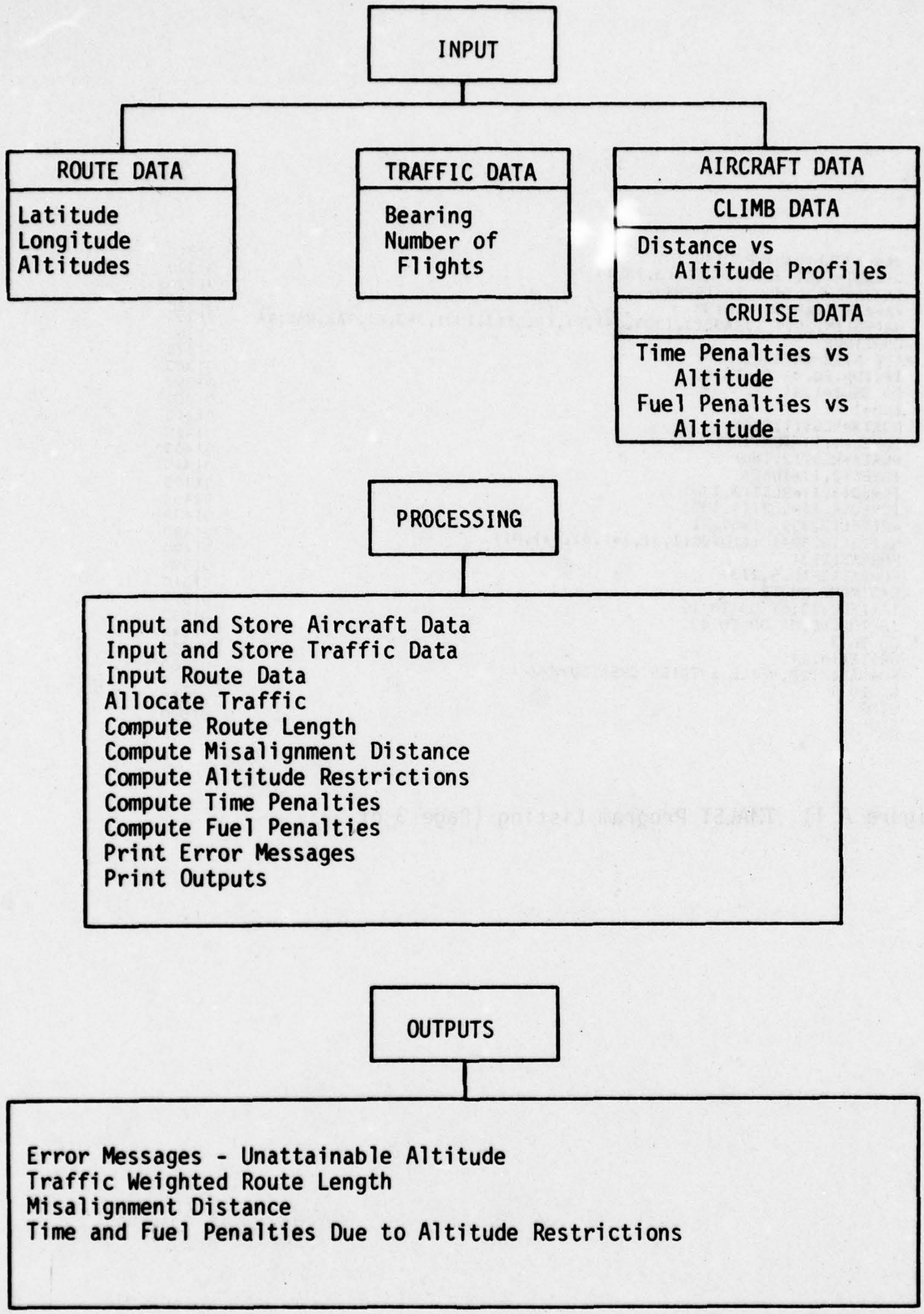


Figure A.12 TEVALP Program Functional Diagram

Word	Name	Description
1	TRAFIC(I)	great circle bearing to (or from) destination (or origin) city (degrees from true north)
2	NTR(I)	number of flights per day between the airports (average of arrivals and departures)

The traffic is sorted in ascending order according to the great circle bearing value. An example of the traffic data for Philadelphia is shown in Figure A.13.

The data contained in the TAPE6 file is derived from aircraft performance tables. This data is input to the program through subroutines CRDATA and CDDATA. In its present configuration TEVALP is capable of analyzing four aircraft using the terminal area during one run. Additional aircraft penalty data may be generated by making multiple runs of TEVALP using different data in TAPE6.

The first 49 records of TAPE6 are read by CDDATA. The remaining 49 records are read by CRDATA. The first record in the file contains the coded names of the four aircraft. This record is organized as follows:

Characters	Name	Format	Description
1-6	—	6X	ignored
7-10	ACV(1)	A4	aircraft 1
11-14	ACV(2)	A4	aircraft 2
15-18	ACV(3)	A4	aircraft 3
19-22	ACV(4)	A4	aircraft 4

The next 48 records are blocked in eight groups of six records each. Groups 1, 2, 3, and 4 are related to the climb profiles of each respective aircraft. Groups 5, 6, 7 and 8 are related to the descent profiles of aircraft 1-4 respectively. Within each group, the six records represent time, distance and fuel burn at six different altitudes. The altitudes do not have to be the same for each aircraft. Thus the profiles may be adapted to each aircraft considered in the analysis. Each profile record is characterized by the following form:

Characters	Name	Format	Description
1-5	—	6X	ignored
6-12	TABLE(1,I,J)	F7.0	altitude (feet)
13-19	TABLE(2,I,J)	F7.4	time (hours)
20-25	TABLE(3,I,J)	F6.2	distance (nm)
26-31	TABLE(4,I,J)	F6.0	fuel (lb)

In TEVALP, the only data in this table that are used consist of the altitude and distance values. Thus the data in the time and fuel columns may be left blank. An example of the first 49 records in TAPE6 is shown in Figure A.14.

Records 50-98 in TAPE6 are similar in organization to the first 49 records. Record 50 is identical to record 1 and the remaining 48 records are organized in eight groups of six records each. However, each record contains only three

```
copy,tapel
00010    39.8750    75.2383    45.0
00020   20.2  4
00030   45.7  5
00040   50.7 25
00050   57.9  3
00060  157.3  3
00070  186.9  1
00080  194.5  5
00090  198.0  4
00100  198.2  7
00110  198.5  1
00120  200.1  2
00130  205.7  2
00140  209.1  5
00150  211.2  1
00160  215.0  3
00170  216.1  1
00180  225.9  3
00190  232.0  1
00200  232.6 12
00210  235.8  2
00220  245.1  1
00230  251.1  3
00240  252.2  1
00250  255.1  4
00260  266.6  1
00270  269.3  3
00280  269.4  1
00290  272.6  1
00300  273.7  3
00310  274.1  1
00320  274.1  3
00330  279.3  3
00340  280.8 21
00350  282.0  1
00360  286.5 13
00370  289.1  8
00380  292.1  1
00390  293.6  7
00400  296.6  2
00410  302.3  2
00420  320.7  3
00430  320.7  1
00440  331.5  2
00450  349.1  2
 END OF INFORMATION ENCOUNTERED.
/
```

terminal radius (nm)

longitude of terminal center

latitude of terminal center

number of flights (departures or arrivals per day)

great circle bearing to city

file line number

Figure A.13 Philadelphia Traffic Data for TEVALP

```
copy,tape6
00090 DC-9B727DC-8B747
00100 00000. 0.0000 00.00 0000.
00110 05000. 0.0320 08.30 0440.
00120 10000. 0.0630 18.40 0880.
00130 10000. 0.0830 23.60 1060.
00140 15000. 0.1290 41.00 1570.
00150 20000. 0.1870 64.90 2170.
00160 00000. 0.0000 00.00 0000.
00170 05000. 0.0480 12.50 0090.
00180 10000. 0.0940 25.10 0160.
00190 10000. 0.1090 29.70 0179.
00200 15000. 0.1360 39.90 0213.
00210 20000. 0.1610 50.30 0239.
00220 00000. 0.0000 00.00 0000.
00230 05000. 0.0300 08.00 0605.
00240 10000. 0.0650 17.30 1220.
00250 10000. 0.0650 17.30 1220.
00260 15000. 0.1270 40.40 2300.
00270 20000. 0.1780 63.00 3105.
00280 00000. 0.0000 00.00 0000.
00290 05000. 0.0560 12.50 0160.
00300 10000. 0.1070 26.30 0270.
00310 10000. 0.1070 26.30 0270.
00320 15000. 0.1580 47.20 0380.
00330 20000. 0.1760 56.90 0430.
00340 00000. 0.0000 00.00 0000.
00350 05000. 0.0320 08.80 1140.
00360 10000. 0.0710 19.30 2270.
00370 10000. 0.0830 22.90 2590.
00380 15000. 0.1240 37.20 3760.
00390 20000. 0.1760 57.90 5040.
00400 00000. 0.0000 00.00 0000.
00410 05000. 0.0650 12.50 0293.
00420 10000. 0.1230 28.70 0522.
00430 10000. 0.1460 36.40 0609.
00440 15000. 0.1730 47.40 0716.
00450 20000. 0.2020 59.80 0807.
00460 00000. 0.0000 00.00 0000.
00470 05000. 0.0280 07.00 1300.
00480 10000. 0.0710 19.00 3300.
00490 10000. 0.0920 27.00 4400.
00500 15000. 0.1480 48.00 6850.
00510 20000. 0.2150 79.00 9650.
00520 00000. 0.0000 00.00 0000.
00530 05000. 0.0430 11.00 0170.
00540 10000. 0.0980 26.90 0340.
00550 10000. 0.1250 35.00 0430.
00560 15000. 0.1540 49.00 0510.
00570 20000. 0.1700 61.50 0570.
```

aircraft type

file line number

altitude (feet)

time to climb or descend (hours)

distance to climb or descend (nm)

fuel to climb or descend (lbs)

Figure A.14 Climb/Descent Data Read by CDDATA Subroutine

data words as opposed to four words used in records 2-49. The three words represent altitude, time penalties and fuel penalties. The penalty values are time (fuel) used at the specified altitude minus the time (fuel) used at a nominal cruise altitude for each aircraft. The penalty values are in terms of hours per nautical mile and pounds of fuel per nautical mile. For example, assume an aircraft normally cruises at 25,000 ft at 400 knots and has a specific range of .05 nm/lb of fuel. Further assume that at 10,000 ft the aircraft flies most efficiently at 350 kts and has a specific range of .04 nm/lb of fuel. The resulting time penalty at 10,000 ft is:

$$\text{Time Penalty} = \frac{1}{250}\left(\frac{hr}{nm}\right) - \frac{1}{400}\left(\frac{hr}{nm}\right) = .0015 \text{ hr/nm}$$

and the fuel penalty is:

$$\text{Fuel Penalty} = \frac{1}{.04}\left(\frac{lb}{nm}\right) - \frac{1}{.05}\left(\frac{lb}{nm}\right) = 5.0 \text{ lb/nm}$$

In the tables, different penalty values are used for arrivals and departures. This is caused by using heavier aircraft weights and lower nominal cruise altitudes for departing aircraft than were used for arriving aircraft. The format for each data record is as follows:

Characters	Name	Format	Description
1-5	—	5X	ignored
6-12	TABLE(1,I,J)	F7.0	altitude (ft)
13-21	TABLE(2,I,J)	F9.6	time penalty (hrs/nm)
22-28	TABLE(3,I,J)	F7.3	fuel penalty (lb/nm)

An example of the altitude restriction penalty tables is shown in Figure A.15.

A.4.3 Output Data

Data produced by TEVALP is output to two files, TAPE2 and TAPE3. The TAPE2 file is used for input to the TACOMP program. The TAPE3 file is printed on the line printer.

The first data that is sent to the TAPE3 file is a header which includes the terminal area identification and the date of the run. Next, the climb - descent data tables and the cruise penalty tables may be sent to the output file TAPE3 if the initial calls to subroutines CDDATA and CRDATA are appropriately specified. Usually this option is not requested once the data tables have been checked for accuracy. Example outputs from these tables are shown in Figures A.16 and A.17.

At this point in the output, arrival and departure data is separated; arrival data is printed first. The next output to TAPE3 is route segment adjustment data. Often the terminal waypoints are read from maps and slight errors in the coordinate values for the boundary point occur. This causes the final segment distance to be in error. This distance error can degrade comparisons of route length between different terminal route structures. In order to compensate for this error an adjustment is made to the final segment

```
00575 DC-9B727DC-8B747
00580 00000. 0.001826 10.529
00590 05000. 0.001557 07.617
00600 10000. 0.001286 05.122
00610 11000. 0.000285 05.344
00620 15000. 0.000146 03.873
00630 20000.-0.000014 02.454
00640 00000. 0.001748 11.708
00650 05000. 0.001479 08.957
00660 10000. 0.001208 06.576
00670 11000. 0.000207 08.090
00680 15000. 0.000068 06.359
00690 20000.-0.000092 04.903
00700 00000. 0.001908 15.795
00710 05000. 0.001639 11.675
00720 10000. 0.001368 08.126
00730 11000. 0.000073 08.997
00740 15000.-0.000060 07.307
00750 20000.-0.000055 04.038
00760 00000. 0.001831 16.536
00770 05000. 0.001562 12.566
00780 10000. 0.001291 09.101
00790 11000.-0.000004 11.451
00800 15000.-0.000137 09.677
00810 20000.-0.000133 06.279
00820 00000. 0.001868 27.084
00830 05000. 0.001599 27.251
00840 10000. 0.001328 15.910
00850 11000. 0.000304 13.671
00860 15000. 0.000135 10.182
00870 20000.-0.000075 07.593
00880 00000. 0.001819 27.489
00890 05000. 0.001550 21.416
00900 10000. 0.001279 16.692
00910 11000. 0.000255 18.830
00920 15000. 0.000087 15.724
00930 20000.-0.000123 13.012
00940 00000. 0.001972 62.416
00950 05000. 0.001703 49.246
00960 10000. 0.001432 37.936
00970 11000. 0.000227 21.164
00980 15000. 0.000095 17.156
00990 20000.-0.000079 15.166
01000 00000. 0.001925 42.390
01010 05000. 0.001657 32.120
01020 10000. 0.001386 23.194
01030 11000. 0.000181 26.741
01040 15000. 0.000048 22.803
01050 20000.-0.000125 21.409
 END OF INFORMATION ENCOUNTERED.
/
```

file line number

altitude (feet)

time penalty multiplier (hours/nm)

fuel penalty multiplier (lbs/nm)

Figure A.15 Cruise Penalty Data Read by CRDATA Subroutine

copy,tape3

TERMINAL AREA DESIGN EVALUATION PROGRAM 82-32-07 77/12/20.

CLIMB/DESCENT TABLES

CLIMB DATA FOR THE DC-9

ALTITUDE	TIME	DIST	FUEL
0.	0.0000	0.00	0.
5000.	.0320	8.30	440.
10000.	.0680	18.40	880.
10000.	.0830	23.60	1060.
15000.	.1290	41.00	1570.
20000.	.1870	64.90	2170.

DESCENT DATA FOR THE DC-9

ALTITUDE	TIME	DIST	FUEL
0.	0.0000	0.00	0.
5000.	.0480	12.50	90.
10000.	.0940	25.10	160.
10000.	.1090	29.70	179.
15000.	.1360	39.90	213.
20000.	.1610	50.30	239.

CLIMB DATA FOR THE B727

ALTITUDE	TIME	DIST	FUEL
0.	0.0000	0.00	0.
5000.	.0300	8.00	605.
10000.	.0650	17.30	1220.
10000.	.0650	17.30	1220.
15000.	.1270	40.40	2300.
20000.	.1780	63.00	3105.

DESCENT DATA FOR THE B727

ALTITUDE	TIME	DIST	FUEL
0.	0.0000	0.00	0.
5000.	.0560	12.50	160.
10000.	.1070	26.30	270.
10000.	.1070	26.30	270.
15000.	.1580	47.20	380.
20000.	.1760	56.90	430.

Figure A.16 Climb/Descent Tables from TEVALP

CRUISE PENALTY TABLES

CLIMB DATA FOR THE DC-9

ALTITUDE	D-TIME	D-FUEL
0.	.002	10.529
5000.	.002	7.617
10000.	.001	5.122
11000.	.000	5.344
15000.	.000	3.873
20000.	-.000	2.454

DESCENT DATA FOR THE DC-9

ALTITUDE	D-TIME	D-FUEL
0.	.002	11.708
5000.	.001	8.957
10000.	.001	6.576
11000.	.000	8.090
15000.	.000	6.359
20000.	-.000	4.903

CLIMB DATA FOR THE B727

ALTITUDE	D-TIME	D-FUEL
0.	.002	15.795
5000.	.002	11.675
10000.	.001	8.126
11000.	.000	8.997
15000.	-.000	7.307
20000.	-.000	4.038

DESCENT DATA FOR THE B727

ALTITUDE	D-TIME	D-FUEL
0.	.002	16.536
5000.	.002	12.566
10000.	.001	9.101
11000.	-.000	11.451
15000.	-.000	9.677
20000.	-.000	6.279

Figure A.17 Cruise Penalty Data from TEVALP

distance to correct for the waypoint coordinate error. This error compensation is pictured in Figure A.18. In the TAPE3 output are found, the route number, the final segment distance, the final segment bearing with respect to true north and, on the next line, the adjusted segment distance. Large discrepancies between the final segment distance and the adjusted segment distance should be checked for erroneous route data or terminal area center coordinate data.

The next output to TAPE3 is the route length data. The route number, route length traffic per route, total aircraft miles per route and the route bearing with respect to the center of the terminal area are recorded for each route. Next the total aircraft miles per route are summed and divided by the number of aircraft using the terminal area to produce a traffic weighted route length. This number is written on TAPE3 along with the total traffic. Next the misalignment distance is computed for all aircraft, summed and divided by the total aircraft to produce a traffic weighted misalignment distance per arrival operation. An example of the final segment distance correction, the route length output and the misalignment distance value outputs are shown in A.19.

The remaining data delivered to TAPE3 concerns the altitude restrictions along each of the routes. Each route segment is analyzed to determine if the aircraft can achieve the specified altitudes and, if so, is the aircraft restricted during descent. If the specified altitude is unattainable according to the descent data tables, then a message "UNATTAINABLE ALTITUDE" is printed along with the route number, the route segment number, the altitude value and the amount of additional milage required to achieve the specified altitude.

If the aircraft achieves the specified altitude and is restricted from achieving a higher altitude, then the message "penalty" is printed along with the route number, route segment number, length of restriction in nautical miles, the fuel burn penalty in pounds, and the time penalty caused by flying at the lower altitude.

After the time and fuel penalties have been determined for each route segment, the traffic weighted time and fuel penalty is computed and sent to the TAPE3 file. The aircraft identification is written on the file along with the fuel penalty, the time penalty, the total traffic, the total fuel penalty and the total time penalty.

The altitude restriction computations are repeated for the remaining three aircraft which completes the analysis for the arriving aircraft. The process is then repeated for departing aircraft and the output for departures is virtually identical in form to the arrival output. An example of the altitude restriction analysis ouput is shown in Figure A.20.

If there is an error in the route input data, such as too many or too few routes, the messages "TOO MANY ROUTES" or "TOO FEW INPUT ROUTES" will appear on the output. The program is currently configured to accept from 1 to 20 arrival or departure routes.

The TAPE2 output file is a condensed version of the TAPE3 file. The file contains 13 records. The first record contains the run identification and the date. The next six records contain arrival data and the final six records

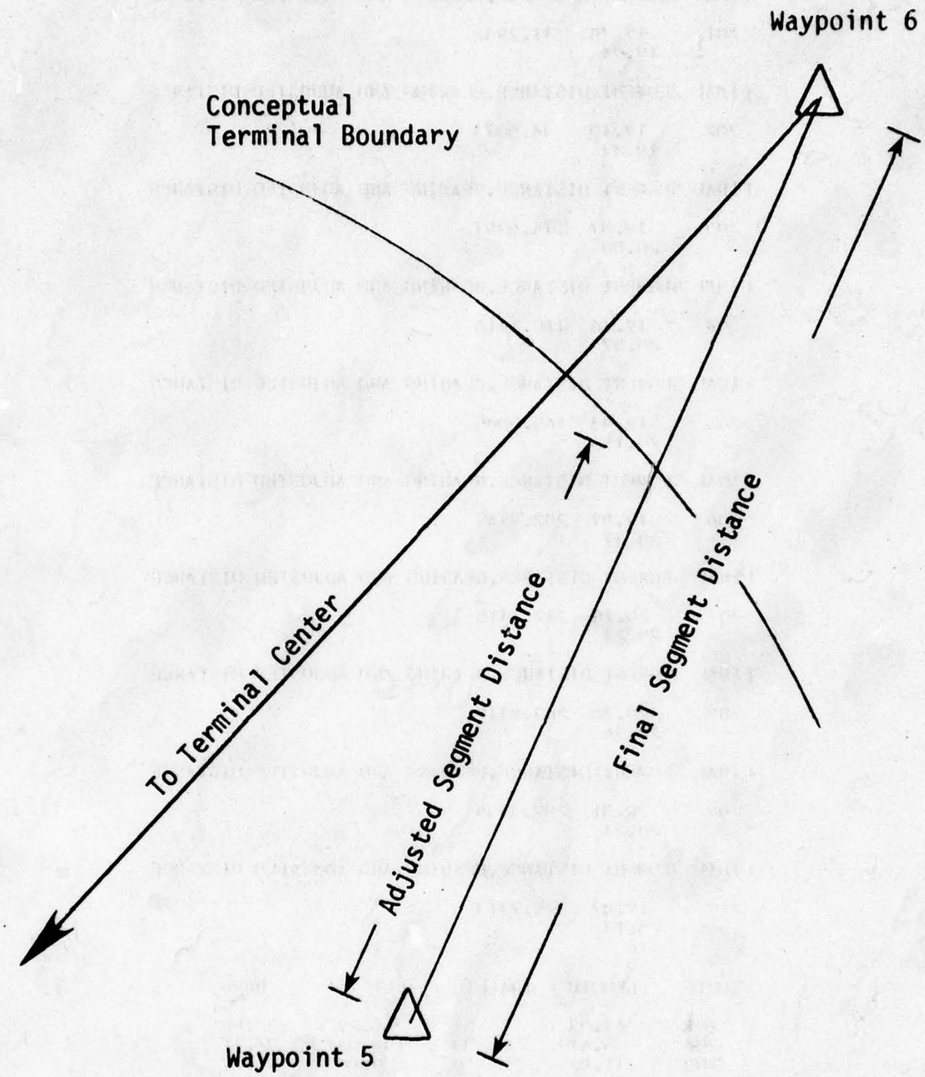


Figure A.18 Final Segment Distance Correction

```
FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 201      19.78    11.2932
         19.94

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 202      19.10    44.5073
         19.47

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 203      19.87    74.6987
         20.80

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 204      19.66   110.1116
         20.57

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 205      19.83   165.5005
         20.18

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 206      19.87   202.9747
         20.37

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 207      20.18   229.2415
         20.23

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 208      20.28   263.9119
         20.36

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 209      20.31   289.3956
         20.24

FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE

 210      19.87   325.7113
         20.17
```

ROUTE	LENGTH	TRAFFIC	FLT MI	BRNG
201	67.07	4	268.29	22.82
202	66.61	33	2198.02	37.11
203	71.82	0	0.00	85.27
204	71.58	0	0.00	109.95
205	52.35	3	157.04	175.22
206	52.54	31	1628.61	191.66
207	44.07	20	881.34	238.59
208	44.20	21	928.15	254.01
209	48.58	58	2817.78	309.07
210	48.51	8	388.10	316.11

```
****ARRIVALS****

TRAFFIC WEIGHTED ROUTE LENGTH      52.06  TRAFFIC LEVEL          178

MISALIGNMENT DISTANCE PER OPERATION =      1.2820
```

Figure A.19 Route Length and Misalignment Distance Output from TEVALP

route	segment	distance (nm)	fuel penalty (lbs)	time penalty (min)

```
ROUTE     FUEL      TIME    TRAFIC   FLT FUEL    FLT TIME

                                                              PENALTY 201   2     .51     5.35    .050
                                                              PENALTY 201   3    3.91    39.34    .372
                                                              PENALTY 201   4    1.41    13.40    .130
                                                              PENALTY 201   5   20.88   187.03   1.853
201       245.1     2.405    115     28190.2     270.542
                                                              PENALTY 202   2     .51     5.35    .050
                                                              PENALTY 202   3    3.91    39.34    .372
                                                              PENALTY 202   4    1.41    13.40    .130
                                                              PENALTY 202   5   20.88   187.03   1.853
202       245.1     2.405     63     15443.3     151.497
*** DC-9  245.1     2.405    178     43633.5     428.038

                                                              PENALTY 201   2     .51     7.55    .052
                                                              PENALTY 201   3    3.91    55.37    .392
                                                              PENALTY 201   4    1.41    18.83    .137
                                                              PENALTY 201   5   20.98   262.38   1.957
                                                           UNATTAINABLE ALTITUDE 201   6    8000.    -.35
201       344.1     2.538    115     39576.1     291.837
                                                              PENALTY 202   2     .51     7.55    .052
                                                              PENALTY 202   3    3.91    55.37    .392
                                                              PENALTY 202   4    1.41    18.83    .137
                                                              PENALTY 202   5   20.98   262.38   1.957
202       344.1     2.538     63     21680.3     159.876
*** B727  344.1     2.538    178     61256.9     451.713

                                                              PENALTY 201   2     .51    12.66    .052
                                                              PENALTY 201   3    3.91    93.28    .389
                                                              PENALTY 201   4    1.41    31.90    .136
                                                              PENALTY 201   5   20.88   447.18   1.942
                                                           UNATTAINABLE ALTITUDE 201   6    8000.   -1.79
201       585.0     2.518    115     67277.4     289.626
                                                              PENALTY 202   2     .51    12.66    .052
                                                              PENALTY 202   3    3.91    93.28    .389
                                                              PENALTY 202   4    1.41    31.90    .136
                                                              PENALTY 202   5   20.88   447.18   1.942
202       585.0     2.518     63     36856.3     158.664
*** DC-8  585.0     2.518    178    104133.7     448.290

                                                              PENALTY 201   2    1.11    42.31    .121
                                                              PENALTY 201   3    4.21   152.59    .446
                                                              PENALTY 201   4    1.71    58.42    .175
                                                              PENALTY 201   5   21.18   680.32   2.106
                                                           UNATTAINABLE ALTITUDE 201   6    8000.   -1.61
201       933.6     2.848    115    107369.2     327.477
                                                              PENALTY 202   2    1.11    42.31    .121
                                                              PENALTY 202   3    4.21   152.59    .446
                                                              PENALTY 202   4    1.71    58.42    .175
                                                              PENALTY 202   5   21.18   680.32   2.106
202       933.6     2.848     63     58819.7     179.401
*** B747  933.6     2.848    178    166188.9     506.878
```

route
segment
altitude (ft)
distance (nm)

Figure A.20 Altitude Restriction Analysis Output from TEVALP

contain departure data in the same format as the arrival data. The records contain the following format and data:

Record	Characters	Variable Names	Format	Description
1	1-10	IDENT	A10	configuration identifier
	11-20	HDATE	A10	date of run
2,8	1-10	DIST	F10.2	traffic weighted route length (nm)
	11-20	ITRAT	I10	total terminal traffic
3,9	1-10	TRWDEL	F10.2	traffic weighted mis-alignment distance(nm)
4-7,10-12	1-10	ACID	A10	aircraft identification
	11-20	DFUEL	F10.1	fuel penalty (lbs)
	21-30	DTIMEM	F10.3	time penalty (min)

An example output to the TAPE2 file is shown in Figure A.21.

A.4.4 Program Description

A.4.4.1 Main Program

A detailed flow diagram of the TEVALP program is shown in Figure A.22 The first part of the program is used to initialize constants and to input terminal identification and aircraft performance values from the TAPE4 and TAPE6 files. The aircraft data is read by the CDDATA and CRDATA subroutines just prior to statement number 10. The latitude and longitude of the terminal center and radius of the terminal area are then read from TAPE5. At 21 the route number and number of waypoints in the route are read from file TAPE4. If an end of file is detected in TAPE4, program control jumps to 40. Otherwise, the route number is decoded and a test is made to determine whether a change from arrivals to departures has occurred in the TAPE4 file. If the change occurs, then program control transfers to 40 after the arrival-departure switch is incremented. If no change in arrival-departure routes occur, then program control transfers to 22 where the route waypoints are read into the IDVEC array. If no read errors are detected and the number of arrival or departure routes does not exceed 20, then the route number is stored in the IRADD array and the number of waypoints in the route is stored in the NRPTS array.

At 26 the waypoint data is extracted from the IDVEC array, the latitude and longitude are placed in the RLST array, and the altitudes are placed in the ALTLST array. At 31 the route segment distances are computed by the LLRAD subroutine and stored in the SEGD array. After 35, the corrected segment distance for the final route segment is calculated and written on the TAPE3 output file. A description of this output is presented in Section A.4.3. Program control returns to 21 where the next route is read. If all arrival or departure routes have been read, then the program jumps to statement 40.

From 40 to 43, the route bearings are sorted according to their bearing from true north. The indices are stored in the IND array; that is, the location IND(1) contains the index of the route with the lowest bearing angle. IND(2)

```
 copy,tape2
82-32-07    77/12/20.                     Identification, date
      52.06          178                  Arrival route length, traffic
       1.28                               Arrival misalignment distance
DC-9                137.3      1.353      DC-9 fuel, time penalty(arrivals)
B727                189.8      1.407      B727  "    "    "    "
DC-8                314.2      1.353      DC-8  "    "    "    "
B747                524.9      1.607      B747  "    "    "    "
      54.22          178                  Departure route length, traffic
        .48                               Departure misalignment distance
DC-9                 16.6       .204      DC-9 fuel, time penalty(departures)
B727                 26.5       .224      B727  "    "    "    "
DC-8                 55.4       .195      DC-8  "    "    "    "
B747                126.9       .263      B747  "    "    "    "
 END OF INFORMATION ENCOUNTERED.
/
```

(Fuel in pounds, time in minutes, distance in nautical miles)

Figure A.21 TAPE2 Output File from TEVALP

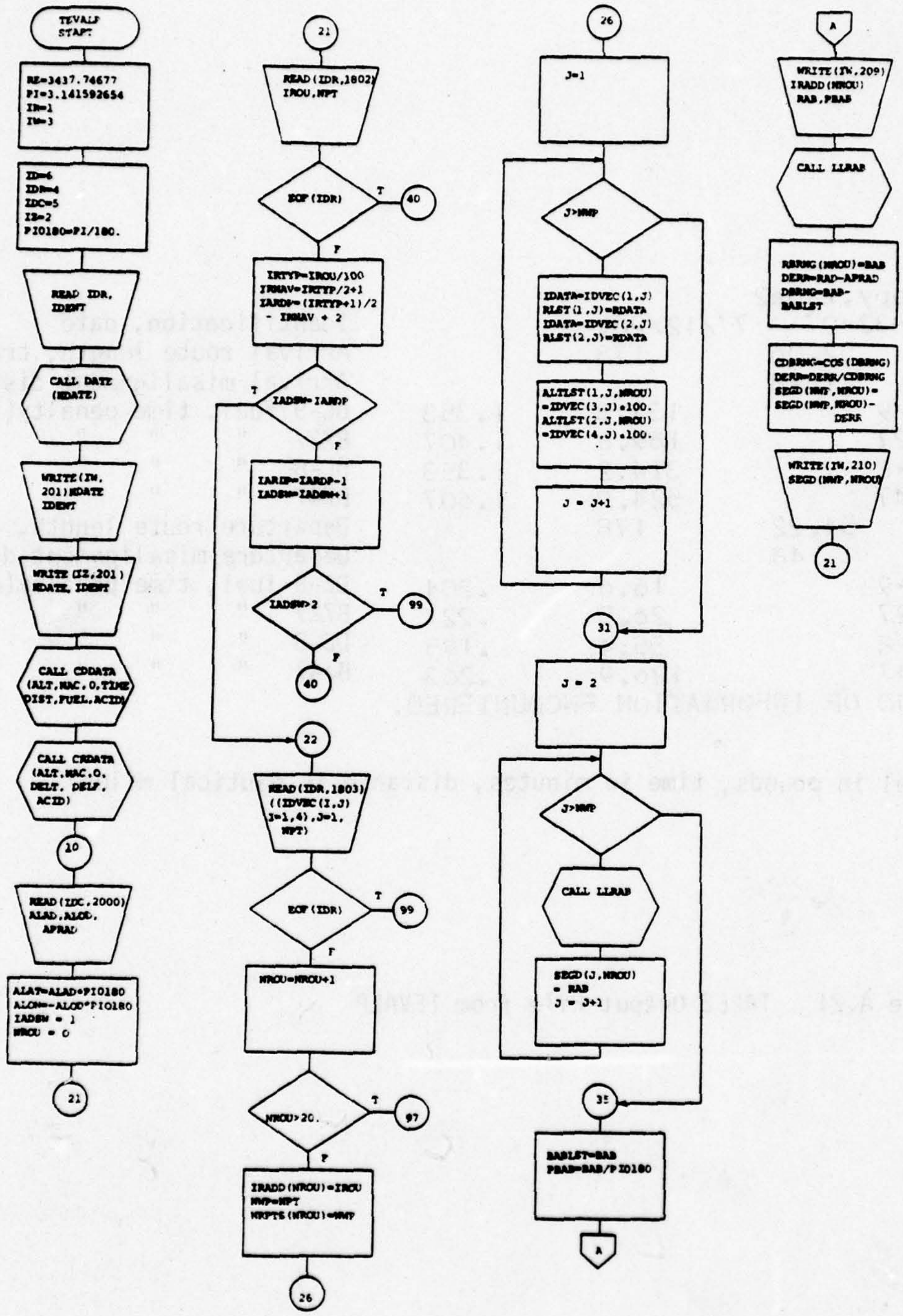


Figure A.22 TEVALP Program Flow Diagram (Pg. 1 of 4)

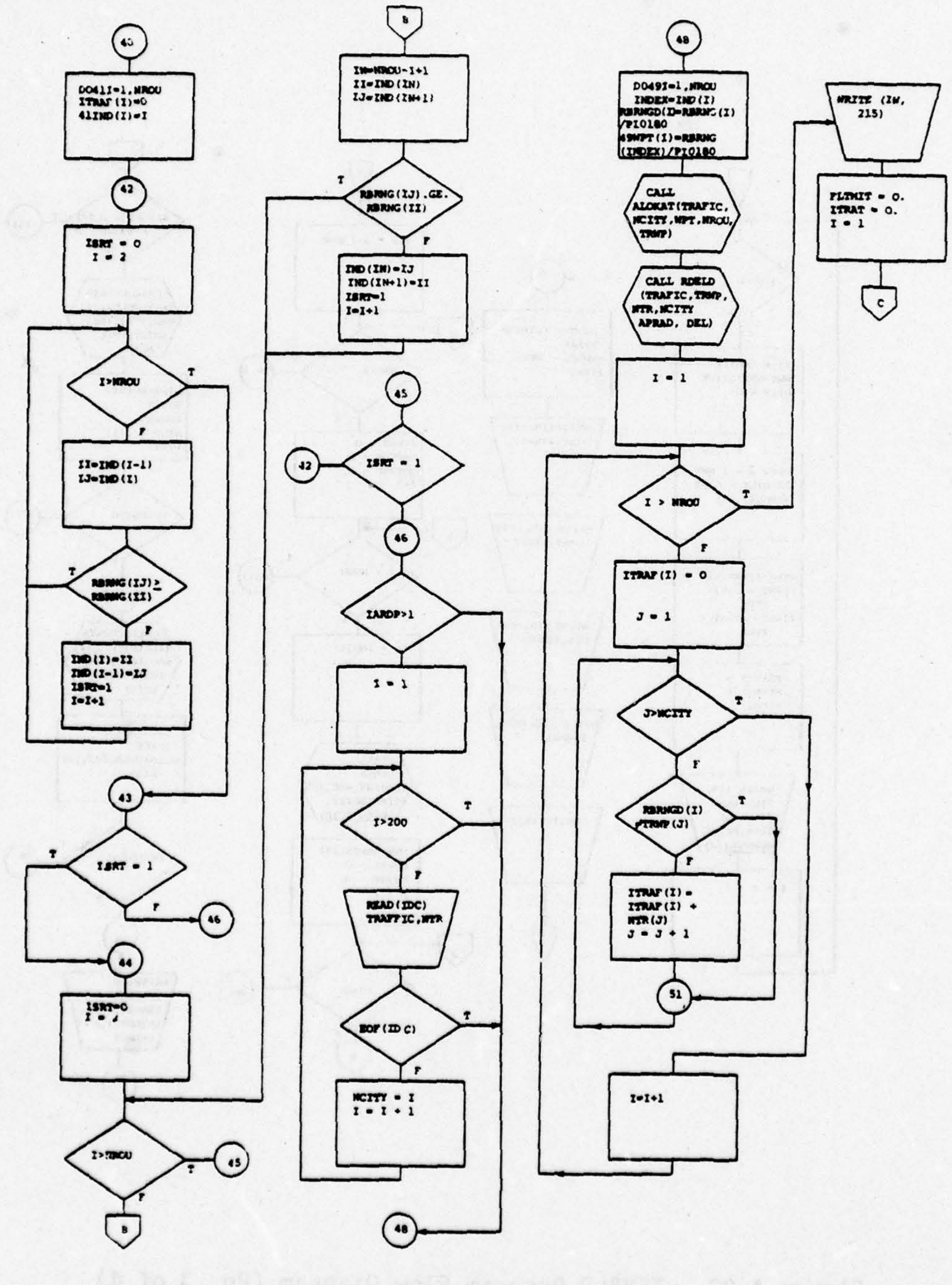


Figure A.22 TEVALP Program Flow Diagram (Pg. 2 of 4)

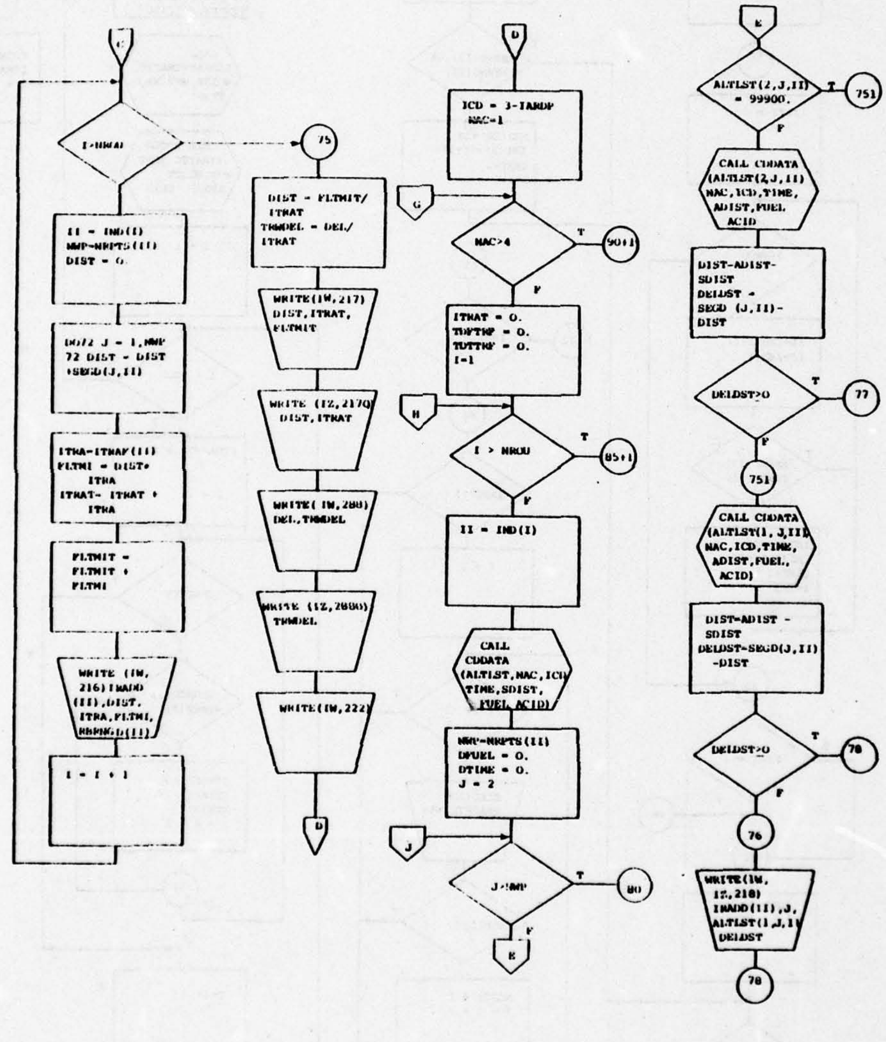


Figure A.22 TEVALP Program Flow Diagram (Pg. 3 of 4)

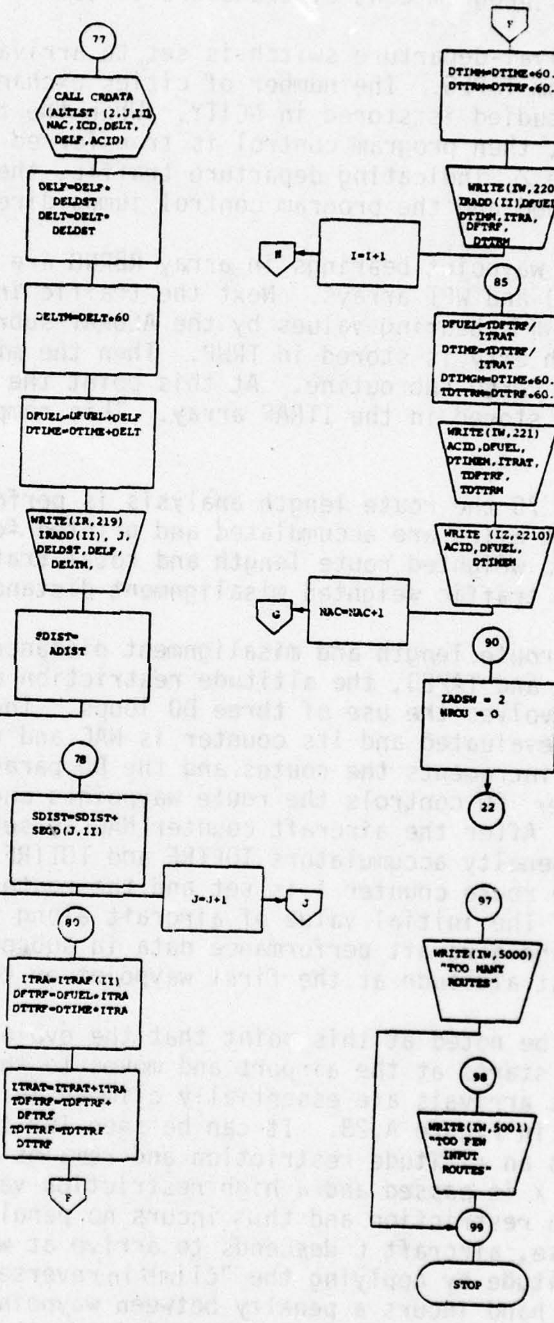


Figure A.22 TEVALP Program Flow Diagram (Pg. 4 of 4)

contains the index of the route with next smallest bearing angle, etc. At 43 a test is made on IRSRT. This indicator is used to determine if the sort is complete. The sort from 40 to 43 is made in the forward direction and the sort from 43 to 45 is made in the backward direction. When either of these passes is made without triggering the IRSRT=1 instruction, the sort is complete and the program control transfers to 46.

If the arrival-departure switch is set to arrivals (IARDP=1) the traffic data is read from TAPE5. The number of cities exchanging traffic with the airport being studied is stored in NCITY. When the traffic file has been read completely, then program control is transferred to 48. If the IARDP switch is set to 2, indicating departure traffic, then the traffic input section is skipped and the program control jumps directly from 46 to 48.

At 48, the waypoint bearings in array RBRNG are converted to degrees and stored in RBRNGD and WPT arrays. Next the traffic in the TRAFIC array is allocated to the WPT bearing values by the ALOKAT subroutine. The waypoint bearing for each city is stored in TRWP. Then the misalignment distance is computed by the RDELD subroutine. At this point the traffic on each route is computed and stored in the ITRAF array. This computation is completed at 51.

From 51 to 75 the route length analysis is performed. The total traffic and total flight miles are accumulated and printed for each route at 75. Next the traffic weighted route length and total traffic data are printed, followed by the traffic weighted misalignment distance value.

After the route length and misalignment distance outputs are written on files TAPE2 and TAPE3, the altitude restriction analysis is performed. This process involves the use of three DO loops. The outer DO selects the aircraft being evaluated and its counter is NAC and runs from 1 to 4. The middle DO loop increments the routes and the DO parameter I runs from 1 to NROU. The inner DO controls the route waypoints and the counter J runs from 2 to NWP. After the aircraft counter NAC is set, the total terminal time and fuel penalty accumulators TDFTRF and TDTTRF are initialized to zero. Then the route counter I is set and the route index II is found from the IND array. The initial value of aircraft along track distance SDIST is found from the aircraft performance data in subroutine CDDATA through using the lowest altitude at the first waypoint on the route.

It should be noted at this point that the evaluation of both arrivals and departures starts at the airport and moves to the terminal boundary. This means that arrivals are essentially climbed in reverse. This procedure is illustrated in Figure A.23. It can be seen for the departures that aircraft A reaches an altitude restriction and remains at the restricted value until waypoint X is passed and a high restriction value is applied. Aircraft B encounters no restriction and thus incurs no penalty at waypoint X. For the arrival case, aircraft C descends to arrive at waypoint Z at exactly the proper altitude by applying the "climb in reverse" procedure. Aircraft D on the other hand incurs a penalty between waypoint Y and Z. However, aircraft D descends from the restricted altitude to achieve the desired altitude at waypoint Z. These climb and descent procedures generally represent realistic climb profiles but are representative of descent profiles for VNAV equipped aircraft only. Non-VNAV equipped arrivals do not have a

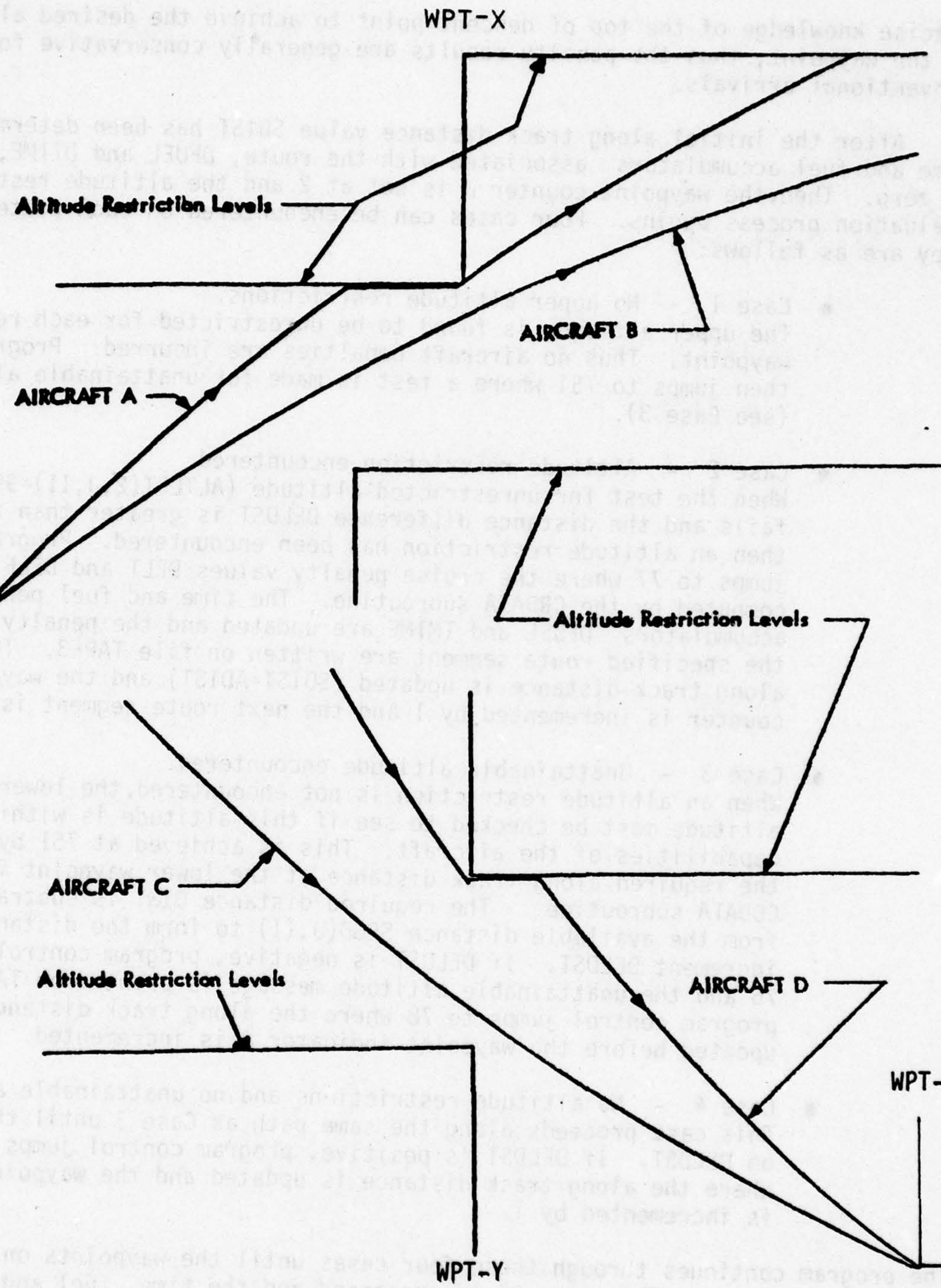


Figure A.23 Climb-Descent Procedure Used in TEVALP

precise knowledge of the top of descent point to achieve the desired altitude at the waypoint, thus the penalty results are generally conservative for these conventional arrivals.

After the initial along track distance value SDIST has been determined, the time and fuel accumulators associated with the route, DFUEL and DTIME, are set to zero. Then, the waypoint counter J is set at 2 and the altitude restriction evaluation process begins. Four cases can be encountered on each route segment. They are as follows:

- Case 1 - No upper altitude restrictions.
  The upper altitude is found to be unrestricted for each remaining waypoint. Thus no aircraft penalties are incurred. Program control then jumps to 751 where a test is made for unattainable altitudes (see Case 3).

- Case 2 - Altitude restriction encountered.
  When the test for unrestricted altitude (ALTLST(2,J,II)=99000) fails and the distance difference DELDST is greater than zero, then an altitude restriction has been encountered. Program control jumps to 77 where the cruise penalty values DELT and DELF are computed by the CRDATA subroutine. The time and fuel penalty accumulators DFUEL and TMIME are updated and the penalty data for the specified route segment are written on file TAPE3. The aircraft along track distance is updated (SDIST=ADIST) and the waypoint counter is incremented by 1 and the next route segment is analyzed.

- Case 3 - Unattainable altitude encountered.
  When an altitude restriction is not encountered, the lower waypoint altitude must be checked to see if this altitude is within the capabilities of the aircraft. This is achieved at 751 by computing the required along track distance at the lower waypoint in the CDDATA subroutine. The required distance DIST is subtracted from the available distance SEGD(J,II) to form the distance increment DELDST. If DELDST is negative, program control goes to 76 and the unattainable altitude message is printed on TAPE3. Then program control jumps to 78 where the along track distance SDIST is updated before the waypoint indicator J is incremented.

- Case 4 - No altitude restrictions and no unattainable altitudes.
  This case proceeds along the same path as Case 3 until the test on DELDST. If DELDST is positive, program control jumps to 78 where the along track distance is updated and the waypoint index is incremented by 1.

The program continues through these four cases until the waypoints on the specified route are depleted. Then step 80 is processed and the time, fuel and traffic accumulators for the terminal area evaluation (TDTTRF, TDFTRF and ITRAT) are updated. The time, fuel and traffic values for the route (DTIMM, DFUEL and ITRA are printed on TAPE3 along with the incremental time and fuel values, DFTRF and DTTRM, which are used to compute the traffic weighted time and fuel penalties for

the airport under consideration. The route counter I is then indexed by 1 and program control returns to the beginning of the route DO loop (location H).

After all routes have been processed, the program control moves to 85 where the traffic weighted time and fuel values for the specified aircraft are computed (DFUEL and DTIME). These data and the aircraft identification ACID are written on both output files, TAPE2 and TAPE3. The aircraft counter, NAC, is incremented and the program returns to the beginning of the outer DO loop (location G).

When all four aircraft have been processed the program control jumps to location 90 and the arrival-departure switch is set to 2 indicating departure traffic. The route counter NROU is reset to zero prior to transferring control back to 22 where the departure routes are read. If all arrivals and departures have been processed at 22, then the end of file is encountered and program control jumps to 99 where the STOP instruction terminates execution.

A.4.4.2 TEVALP Subprograms (See Figures A.24-A.29)

The CRDATA subroutine is used to input aircraft cruise penalty data and to compute time and fuel penalty multipliers. The input parameters for CRDATA are aircraft altitude, ALT, aircraft identification number, NAC, and climb-descent indicator, ICD. The output values from the subroutine are the time penalty multipier, DELT, the fuel penalty multiplier, DELF and the alphanumeric aircraft identifier, ACID. A call to CRDATA with ICD=0 will cause the aircraft cruise data to be read from file TAPE6 and stored in the array called TABLE. If ICD<0, a return is made to the calling program. If ICD=0, the aircraft data is written on file TAPE3 before the RETURN instruction is processed. A call to CRDATA with ICD>0 requests that penalty data be obtained from the aircraft data. An index M is computed at 20 which indicates which data records in the TABLE array are to be used. The input altitude ALT is tested with the altitude values in TABLE until the test ALT≤TABLE(1,I,M) is true or until all six applicable altitude values in TABLE have been tested. Control then jumps to 22 where a linear interpolation on the TABLE values is performed using ALT as the independent variable and time and fuel multipliers, DELT and DELF, as the dependent variables. Control is then returned to the calling program.

The CDDATA subroutine is very similar to the CRDATA subroutine. The major differences concern the fact that the TABLE array contains time, distance and fuel to climb (or descend) values rather than cruise penalty multipliers. The only value used by TEVALP is the distance to climb(or descend) value. The input, output and interpolation aspects of CDDATA are the same as those found in CRDATA.

The RDELD subroutine simply computes the terminal area misalignment distance for all traffic in the NTR array. The input data are the great circle bearings to the destination (or origin) cities, TRAFIC; the arrival or departure waypoint bearing used to each of cities, ATRWP; the number of flights to (or from) each city, NTR; the number of cities, NCITY; and the terminal radius value, RAD. The misalignment distance DEL is initialized to zero and then accummulated in the DO loop by the misalignment distance formula (see Section 3.2, Figure 6).

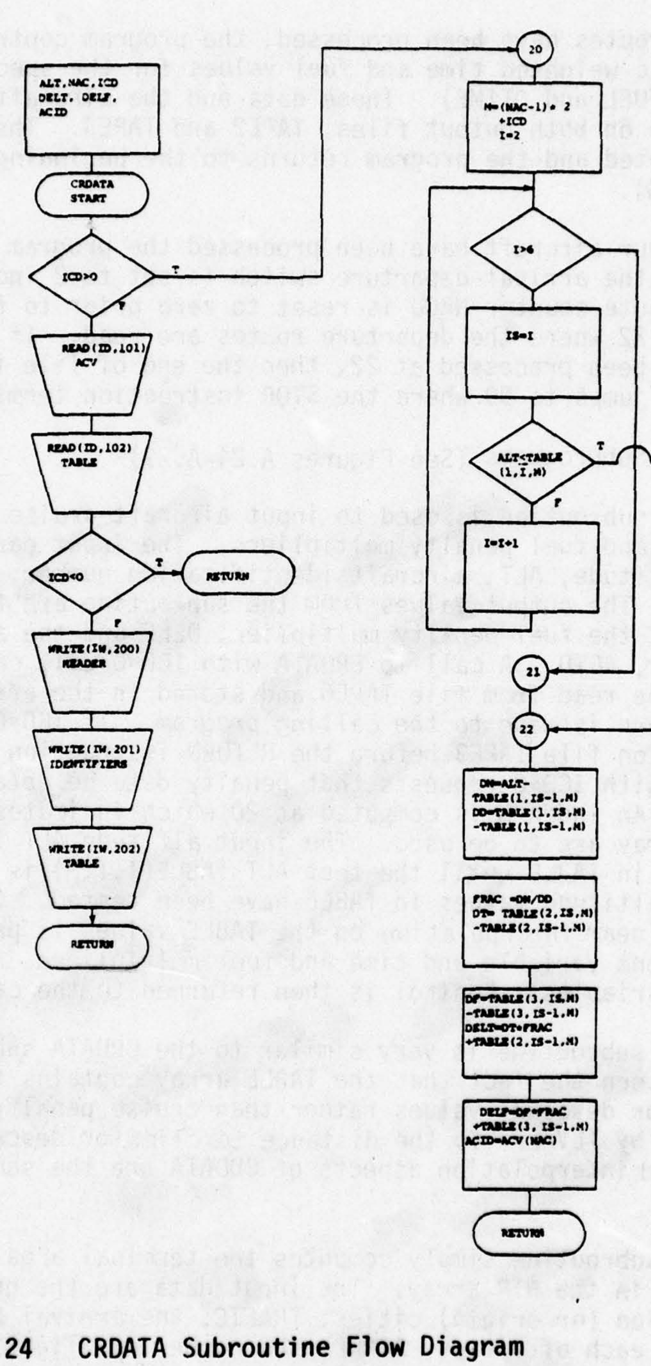


Figure A.24 CRDATA Subroutine Flow Diagram

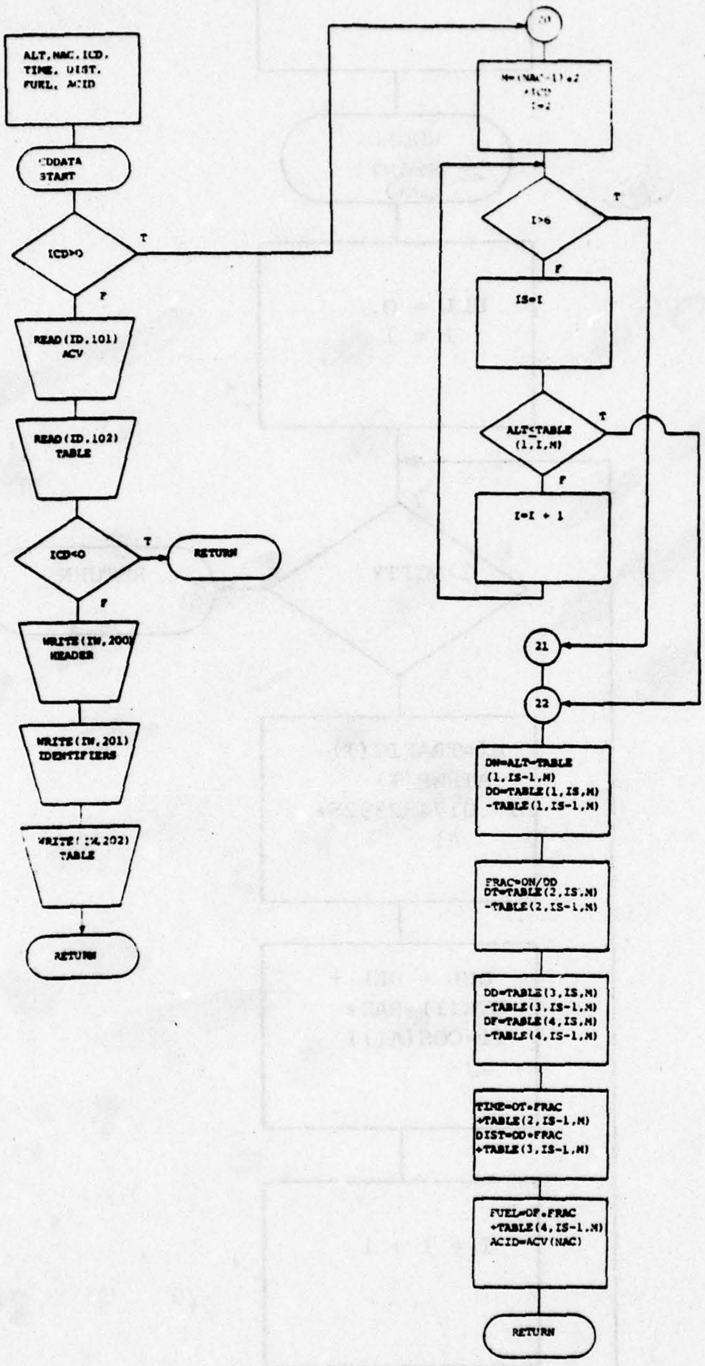


Figure A.25 CDDATA Subroutine Flow Diagram

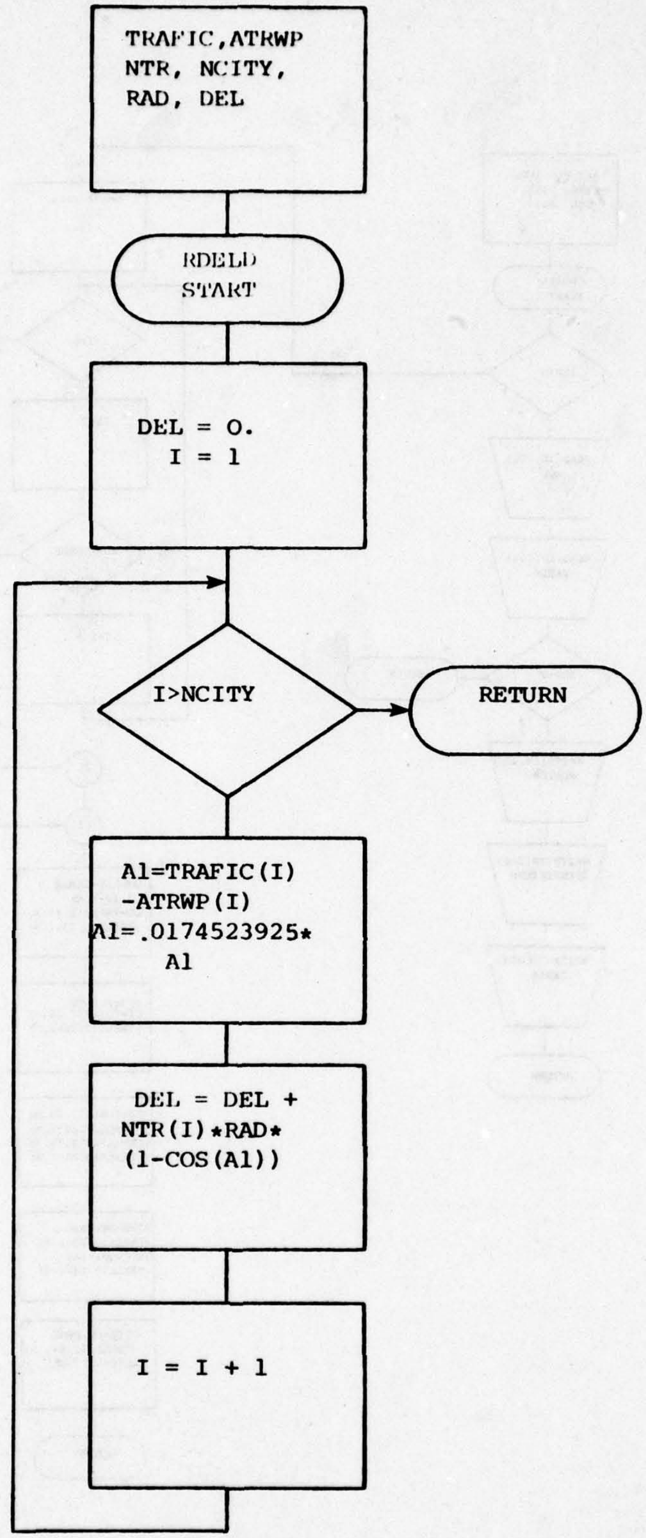


Figure A.26 RDELD Subroutine Flow Diagram

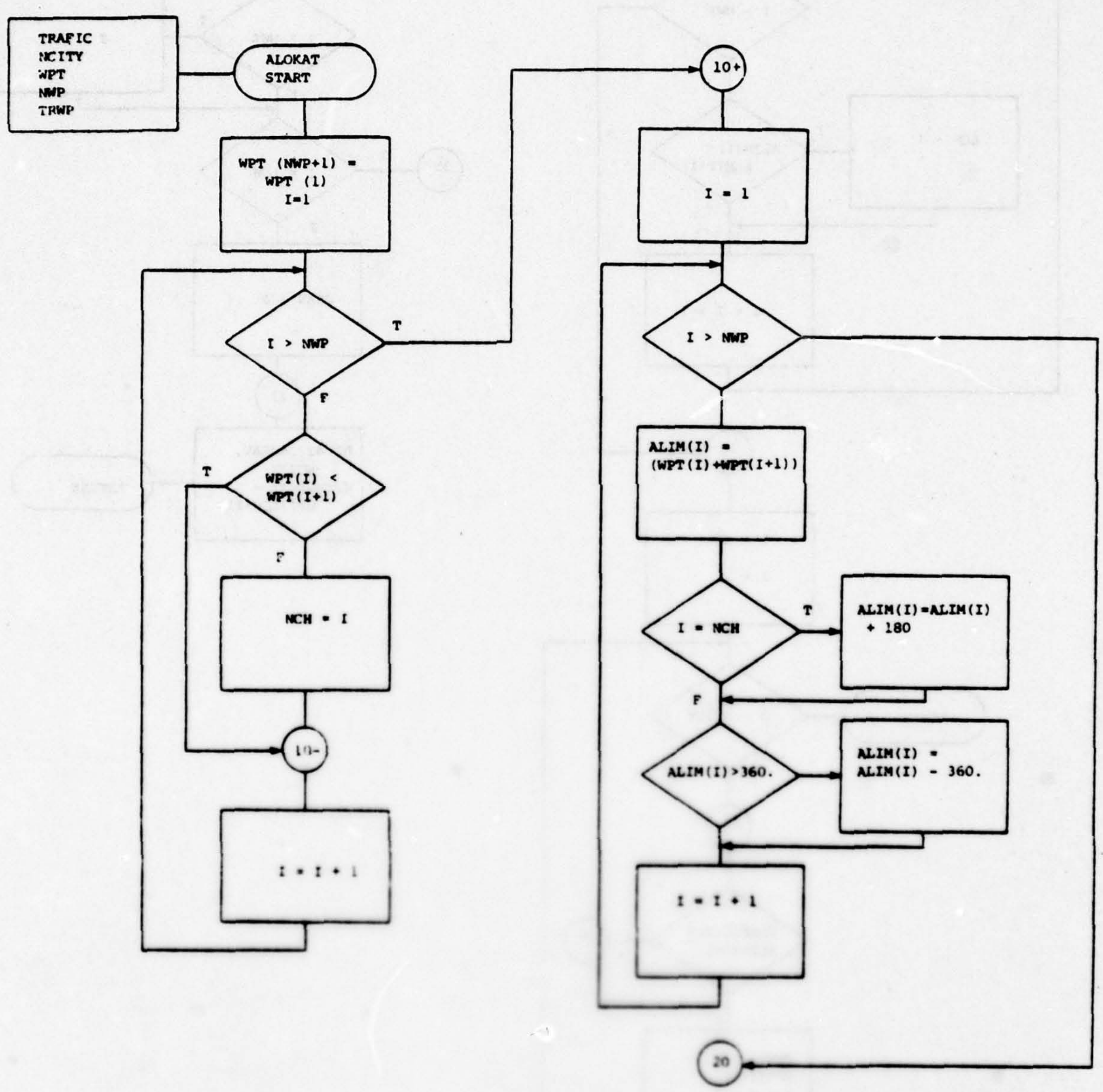


Figure A.27 ALOKAT Subroutine Flow Diagram (Pg. 1 of 2)

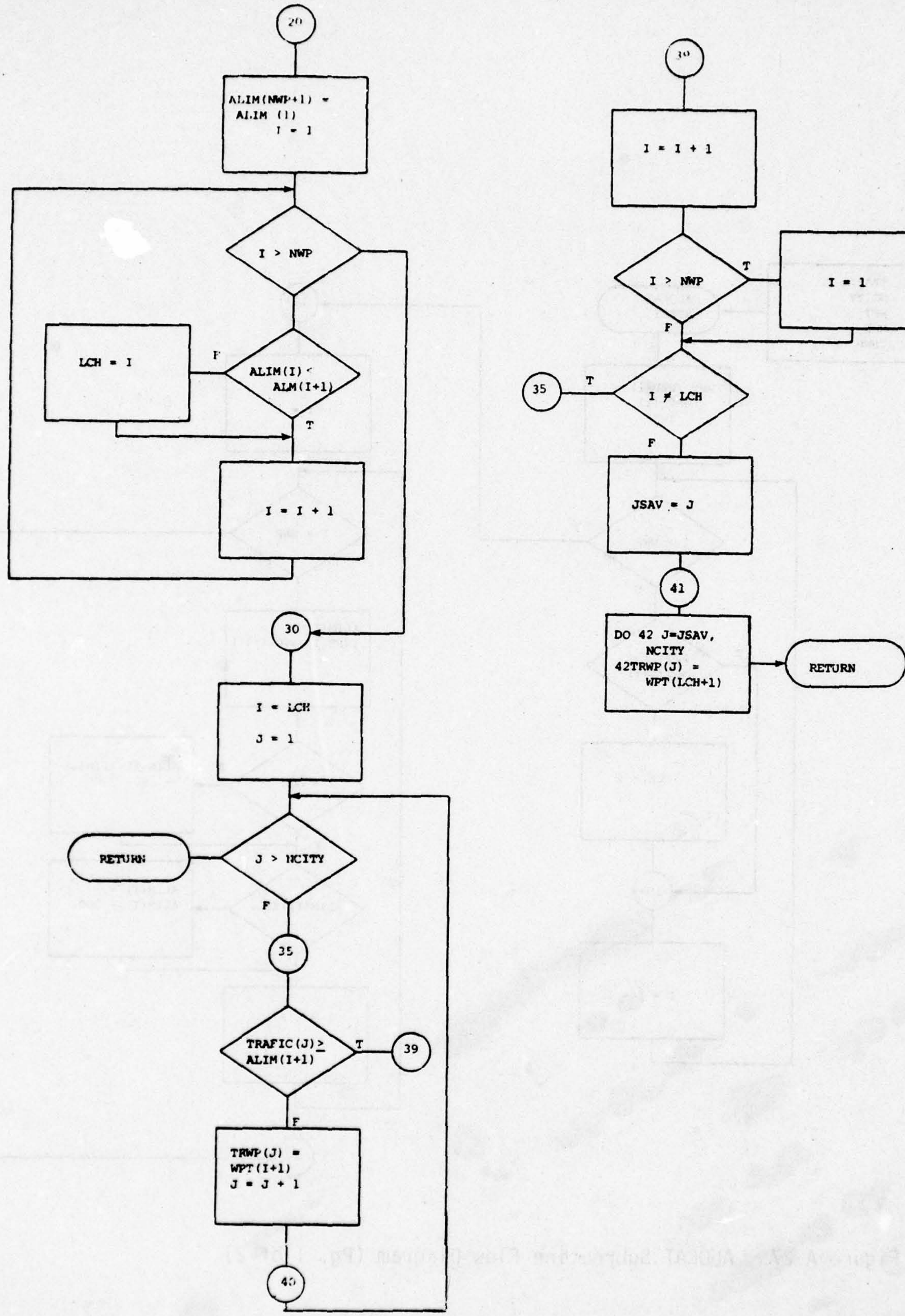


Figure A.27 ALOKAT Subroutine Flow Diagram (Pg. 2 of 2)

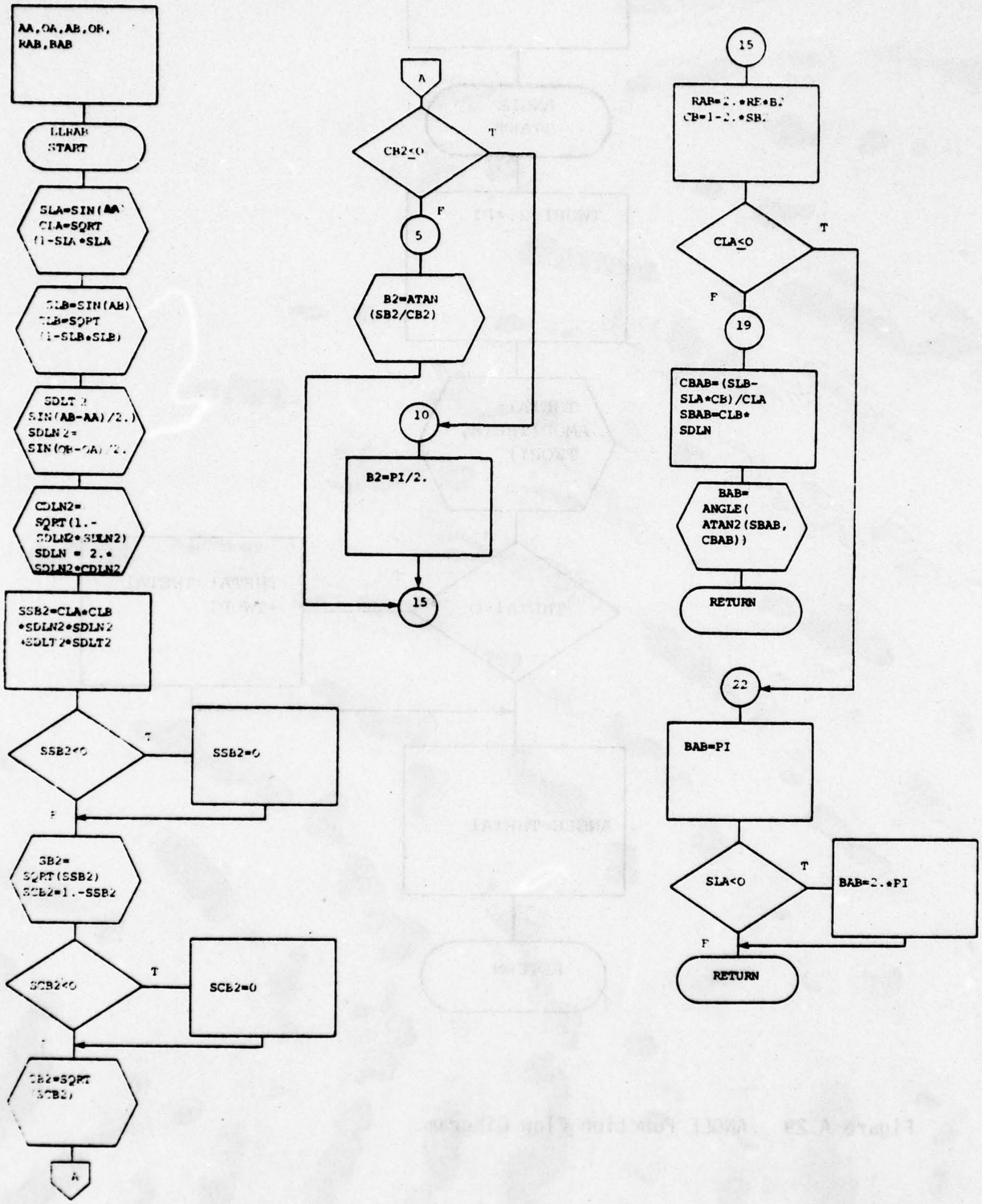


Figure A.28 LLRAB Subroutine Flow Diagram

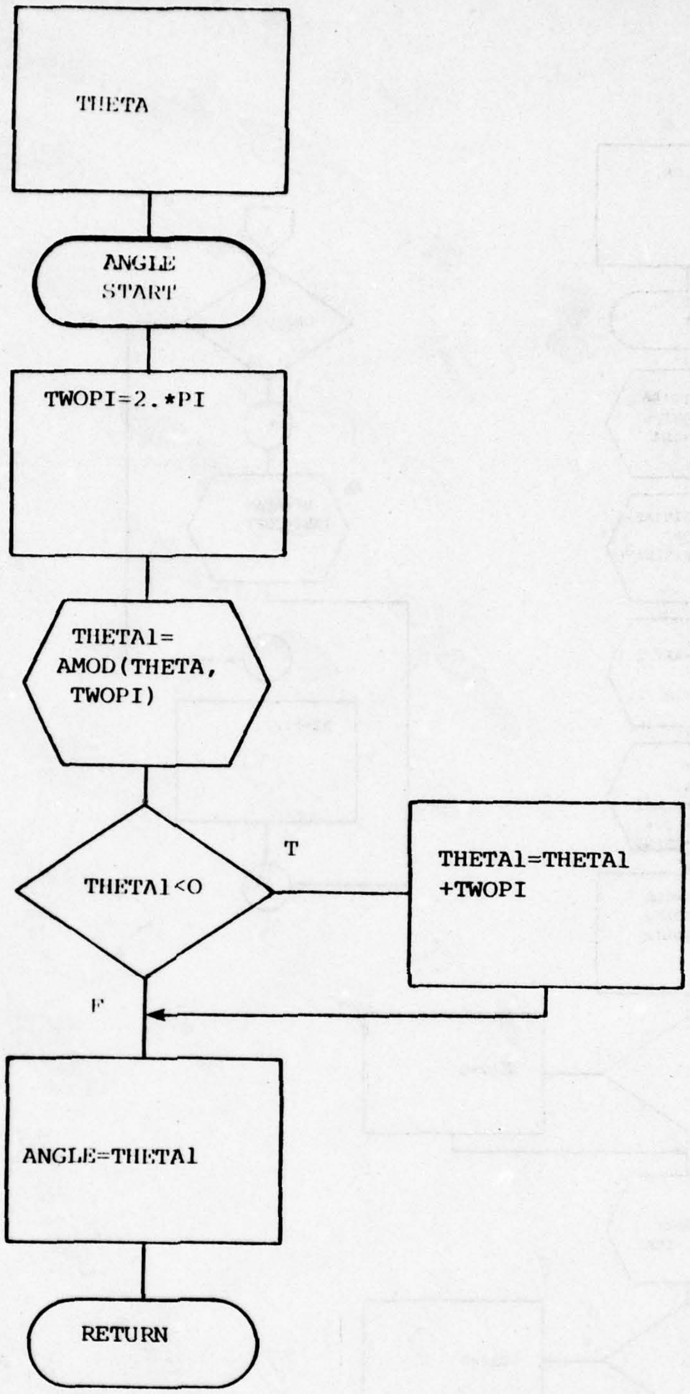


Figure A.29 ANGLE Function Flow Diagram

The ALOKAT subroutine is used to allocate traffic to the various terminal waypoints. Data is input to ALOKAT through the subroutine arguments. The great circle bearings to the destination (origin) cities are found in the TRAFIC array, the number of cities is found in NCITY, the waypoint bearings with respect to the terminal city are in the WPT array and the number of waypoints is in NWP. The output of ALOKAT is an array called TRWP which is an array of waypoint bearings from WPT that correspond to the city bearings in TRAFIC. In other words, the city whose great circle bearing is in location TRAFIC(I) uses the waypoint bearing that is found in TRWP(I). The bearings in TRAFIC are assumed to be in ascending order. The waypoint bearings are assumed to be in clockwise order. All bearing angles should be between 0° and 360° degrees. The initial part of the subroutine assigns the same value to the NWP+1 waypoint bearing as is assigned to waypoint bearing 1. Then a DO loop is used to determine at what index value the waypoint bearings switch by 360°, that is if WPT(I) is 330° and WPT(I+1) is 10° then NCH is assigned the value of I. From 10 to 20 the bearing angle limits ALIM are computed by averaging successive waypoint bearings. If the waypoints are on each side of true north then the angle is in error by ±180°. This occurs at the waypoint index I=NCH. If the bearing angle exceeds 360°, then the waypoint bearing is reduced by 360° to place it between 0° and 360°. From 20-30 the index before which the bearing angle limits ALIM(I) pass through true north is saved in LCH. At 30 the index I is set at LCH and J is set at 1. This represents starting at true north for TRAFIC(J) and ALIM(I+1). When TRAFIC(J) remains less than ALIM(I+1), (that is, the traffic bearing angle remains less than the limit bearing angle) then TRWP(J) is assigned the value WPT(I+1). This continues until the bearing angle test fails at which point the program jumps to 39, increments the index I and tests for I>NWP. If I exceeds NWP it is reset to 1. If I has not yet reached the value LCH, which was its initial value, then the program control returns to 35 where the waypoint assignments continue. When I reaches the value LCH, the remaining points are assigned the value WPT(LCH+1) and the program returns to the calling program with the TRWP values assigned to one of the waypoint bearing values.

The remaining subprograms called by TEVALP are LLRAB and ANGLE. The LLRAB program is used to convert two pair of latitude-longitude coordinates to range and bearing coordinates on a spherical earth. The ANGLE function is used to return an angular value between 0° and 360°.

A.4.5 Program Listing

Listings of the TEVALP main program and the ALOKAT, CDDATA, CRDATA, RDELD, LLRAB and ANGLE subprograms are shown in Figures A.30-A.36.

A.5 PROGRAM TACOMP

A.5.1 Purpose of Program

The TACOMP program is used to compare the user benefits associated with two terminal route structures. The program uses the output from the TEVALP program to perform these user benefit analyses. The benefit parameters that are computed are time and fuel savings for arrivals, departures and the average of arrivals and departures. In the Reference 1 study, the route structures that

```
      PROGRAM TEVALP(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,TAPE5,TAPE6)
C     PROGRAM TO EVALUATE THE TRAFFIC WEIGHTED ROUTE LENGTH
C     AND ALTITUDE CHARACTERISTICS OF TERMINAL AREA DESIGNS
      DIMENSION IDVEC(4,18),RLST(2,18),APNAME(5),ICHID(3),IRADD(20)
      DIMENSION NRPTS(20),RBRNG(20),SEGD(18,20),TRAFIC(200),NTR(200),IND
     1(20)
      DIMENSION ITRAF(20),ALTLST(2,18,20),WPT(26),TRWP(200)
      DIMENSION RBRNGD(20)
      EQUIVALENCE(RDATA,IDATA)
      COMMON RE,PI,IR,IW,ID
      RE=3437.74677
      PI=3.141592654
      IR=1
      IW=3
      ID=6
      IDR=4
      IDC=5
      IZ=2
      PIO180=PI/180.
      READ(IDR,1700)IDENT
 1700 FORMAT(A10)
      CALL DATE(HDATE)
C     WRITE HEADER
      WRITE(IW,201) IDENT,HDATE
      WRITE(IZ,2010) IDENT,HDATE
 2010 FORMAT(2A10)
 201  FORMAT(/T2,*TERMINAL AREA DESIGN EVALUATION PROGRAM  *,2A10/)
C     READ PERFORMANCE DATA
      CALL CDDATA(ALT,NAC,O,TIME,DIST,FUEL,ACID)
      CALL CRDATA(ALT,NAC,O,DELT,DELF,ACID)
 10   READ(IDC,2000) ALAD,ALOD,APRAD
 2000 FORMAT(5X,3F10.5)
      ALAT=ALAD*PIO180
      ALON=-ALOD*PIO180
C     GET ROUTE DATA
      IADSW=1
      NROU=0
 21   READ(IDR,1802) IROU,NPT
 1802 FORMAT(2I3)
      IF(EOF(IDR).NE.0.) GO TO 40
      IRTYP=IROU/100
      IRNAV=IRTYP/2+1
      IARDP=(IRTYP+1)/2-IRNAV+2
      IF(IADSW.EQ.IARDP) GO TO 22
      IARDP=IARDP-1
      IADSW=IADSW+1
      IF(IADSW.GT.2) GO TO 99
      GO TO 40
 22   READ(IDR,1803) ((IDVEC(I,J),I=1,4),J=1,NPT)
 1803 FORMAT(2F10.5,2I3)
      IF(EOF(IDR).NE.0.) GO TO 99
      NROU=NROU+1
      IF(NROU.GT.20) GO TO 97
      IRADD(NROU)=IROU
      NWP=NPT
      NRPTS(NROU)=NWP
 25   CONTINUE
      DO 31 J=1,NWP
      IDATA=IDVEC(1,J)
      RLST(1,J)=RDATA
```

Figure A.30 TEVALP Program Listing (Page 1 of 4)

```
      IDATA=IDVEC(2,J)
      RLST(2,J)=RDATA
      ALTLST(1,J,NROU)=IDVEC(3,J)*100.
31    ALTLST(2,J,NROU)=IDVEC(4,J)*100.
      DO 35 J=2,NWP
      CALL LLRAB(RLST(1,J-1)*PIO180,-RLST(2,J-1)*PIO180,
     1RLST(1,J)*PIO180,-RLST(2,J)*PIO180,RAB,BAB)
      SEGD(J,NROU)=RAB
35    CONTINUE
      BABLST=BAB
      PBAB=BAB/PIO180
      WRITE(IW,208)
208   FORMAT(/*FINAL SEGMENT DISTANCE,BEARING AND ADJUSTED DISTANCE*/)
      WRITE(IW,209) IRADD(NROU),RAB,PBAB
209   FORMAT(T2,I3,F10.2,F10.4)
      CALL LLRAB(ALAT,ALON,RLST(1,NWP)*PIO180,-RLST(2,NWP)*PIO180,
     1RAB,BAB)
      RBRNG(NROU)=BAB
      DERR=RAB-APRAD
      DBRNG=BAB-BABLST
      CDBRNG=COS(DBRNG)
      DERR=DERR/CDBRNG
      SEGD(NWP,NROU)=SEGD(NWP,NROU)-DERR
      WRITE(IW,210) SEGD(NWP,NROU)
210   FORMAT(T4,F10.2)
      GO TO 21
40    CONTINUE
C     SORT
      DO 41 I=1,NROU
      ITRAF(I)=0
41    IND(I)=I
C     SORT FORWARD
42    ISRT=0
      DO 43 I=2,NROU
      II=IND(I-1)
      IJ=IND(I)
      IF(RBRNG(IJ).GE.RBRNG(II)) GO TO 43
      IND(I)=II
      IND(I-1)=IJ
      ISRT=1
43    CONTINUE
      IF(ISRT.EQ.1) GO TO 44
      GO TO 46
C SORT BACKWARD
44    ISRT=0
      DO 45 I=2,NROU
      IN=NROU-I+1
      II=IND(IN)
      IJ=IND(IN+1)
      IF(RBRNG(IJ).GE.RBRNG(II)) GO TO 45
      IND(IN)=IJ
      IND(IN+1)=II
      ISRT=1
45    CONTINUE
      IF(ISRT.EQ.1) GO TO 42
C     SORT COMPLETE, SECTORIZE TRAFFIC
46    CONTINUE
      IF(IARDP.GT.1) GO TO 48
      DO 47 I=1,200
      READ(IDC,*) IGARB,TRAFIC(I),NTR(I)
```

Figure A.30 TEVALP Program Listing (Page 2 of 4)

```
      IF(EOF(IDC).NE.0.) GO TO 48
47    NCITY=I
48    CONTINUE
      DO 49 I=1,NROU
      INDEX=IND(I)
      RBRNGD(I)=RBRNG(I)/PIO180
49    WPT(I)=RBRNG(INDEX)/PIO180
      CALL ALOKAT(TRAFIC,NCITY,WPT,NROU,TRWP)
      CALL RDELD(TRAFIC,TRWP,NTR,NCITY,APRAD,DEL)
      DO 51 I=1,NROU
      ITRAF(I)=0
      DO 51 J=1,NCITY
      IF(RBRNGD(I).NE.TRWP(J)) GO TO 51
      ITRAF(I)=ITRAF(I)+NTR(J)
51    CONTINUE
C     ROUTE LENGTH ANALYSIS
70    WRITE(IW,215)
215   FORMAT(//T2,*ROUTE     LENGTH    TRAFFIC     FLT MI       BRNG*/)
      FLTMIT=0.
      ITRAT=0
      DO 75 I=1,NROU
      II=IND(I)
      NWP=NRPTS(II)
      DIST=0.
      DO 72 J=1,NWP
72    DIST=DIST+SEGD(J,II)
      ITRA=ITRAF(II)
      FLTMI=DIST*ITRA
      ITRAT=ITRAT+ITRA
      FLTMIT=FLTMIT+FLTMI
75    WRITE(IW,216) IRADD(II),DIST,ITRA,FLTMI,RBRNGD(II)
216   FORMAT(T3,I4,F10.2,I10,2F10.2)
      DIST=FLTMIT/ITRAT
      TRWDEL=DEL/ITRAT
      IF(IARDP.EQ.1) WRITE(IW,230)
      IF(IARDP.EQ.2) WRITE(IW,231)
230   FORMAT(T10,16H****ARRIVALS****)
231   FORMAT(T10,18H****DEPARTURES****)
      WRITE(IZ,2170) DIST,ITRAT
2170  FORMAT(F10.2,I10)
      WRITE(IW,217) DIST,ITRAT
217   FORMAT(/T2,30HTRAFFIC WEIGHTED ROUTE LENGTH ,F10.2,
     116H  TRAFFIC LEVEL ,I10/)
      WRITE(IW,288) TRWDEL
288   FORMAT(39H MISALIGNMENT DISTANCE PER OPERATION = ,F10.4/)
      WRITE(IZ,2880) TRWDEL
2880  FORMAT(F10.2)
C     ALTITUDE RESTRICTION ANALYSIS
      WRITE(IW,222)
222   FORMAT(//T2,*ROUTE      FUEL       TIME      TRAFIC  FLT FUEL  FLT TIM
     1E*/)
      ICD=3-IARDP
      DO 90  NAC=1,4
      ITRAT=0
      TDFTRF=0.
      TDTTRF=0.
      DO 85 I=1,NROU
      II=IND(I)
      CALL CDDATA(ALTLST(1,1,II),NAC,ICD,TIME,SDIST,FUEL,ACID)
      NWP=NRPTS(II)
```

Figure A.30 TEVALP Program Listing (Page 3 of 4)

```
      DFUEL=0.
      DTIME=0.
      DO 80 J=2,NWP
C     FIND DISTANCE TO MAX ALTITUDE
      IF(ALTLST(2,J,II).EQ.99900.) GO TO 751
      CALL CDDATA(ALTLST(2,J,II),NAC,ICD,TIME,ADIST,FUEL,ACID)
      DIST=ADIST-SDIST
      DELDST=SEGD(J,II)-DIST
      IF(DELDST.GE.0.) GO TO 77
751   CALL CDDATA(ALTLST(1,J,II),NAC,ICD,TIME,ADIST,FUEL,ACID)
      DIST=ADIST-SDIST
      DELDST=SEGD(J,II)-DIST
      IF(DELDST.GE.0.) GO TO 78
76    WRITE(IW,218) IRADD(II),J,ALTLST(1,J,II),DELDST
218   FORMAT(T59,*UNATTAINABLE ALTITUDE*,2I4,F10.0,F10.2)
      GO TO 78
C     PENALTY
77    CALL CRDATA(ALTLST(2,J,II),NAC,ICD,DELT,DELF,ACID)
      DELF=DELF*DELDST
      DELT=DELT*DELDST
      DFUEL=DFUEL+DELF
      DTIME=DTIME+DELT
      DELTM=DELT*60.
      WRITE(IW,219) IRADD(II),J,DELDST,DELF,DELTM
219   FORMAT(T60,*PENALTY*,2I4,2F10.2,2F10.3)
      SDIST=ADIST
      GO TO 80
78    SDIST=SDIST+SEGD(J,II)
80    CONTINUE
      ITRA=ITRAF(II)
      DFTRF=DFUEL*ITRA
      DTTRF=DTIME*ITRA
      ITRAT=ITRAT+ITRA
      TDFTRF=TDFTRF+DFTRF
      TDTTRF=TDTTRF+DTTRF
      DTIMM=DTIME*60.
      DTTRM=DTTRF*60.
      WRITE(IW,220) IRADD(II),DFUEL,DTIMM,ITRA,DFTRF,DTTRM
      GO TO 85
220   FORMAT(T2,I3,F10.1,F10.3,I10,F10.1,F10.3)
85    CONTINUE
      DFUEL=TDFTRF/ITRAT
      DTIME=TDTTRF/ITRAT
      DTIMEM=DTIME*60.
      TDTTRM=TDTTRF*60.
      WRITE(IW,221) ACID,DFUEL,DTIMEM,ITRAT,TDFTRF,TDTTRM
      WRITE(IZ,2210) ACID,DFUEL,DTIMEM
2210  FORMAT(A10,F10.1,F10.3)
90    CONTINUE
221   FORMAT(/4H*** ,A4,F7.1,F10.3,I10,F10.1,F10.3/)
      IADSW=2
      NROU=0
      GO TO 22
97    WRITE(IW,5000)
5000  FORMAT(/*  TOO MANY ROUTES*/)
      GO TO 99
98    WRITE(IW,5001)
5001  FORMAT(/*  TOO FEW INPUT ROUTES*/)
99    STOP
      END
```

Figure A.30 TEVALP Program Listing (Page 4 of 4)

```
      SUBROUTINE ALOKAT(TRAFIC,NCITY,WPT,NWP,TRWP)
      DIMENSION WPT(26),TRAFIC(200),ALIM(26),TRWP(200)
      WPT(NWP+1)=WPT(1)
      DO 10 I=1,NWP
      IF(WPT(I).LT.WPT(I+1)) GO TO 10
      NCH=I
10    CONTINUE
      DO 20 I=1,NWP
      ALIM(I)=(WPT(I)+WPT(I+1))/2.
      IF(I.EQ.NCH) ALIM(I)=ALIM(I)+180.
      IF(ALIM(I).GE.360.) ALIM(I)=ALIM(I)-360.
20    CONTINUE
      ALIM(NWP+1)=ALIM(1)
      DO 30 I=1,NWP
      IF(ALIM(I).LT.ALIM(I+1)) GO TO 30
      LCH=I
30    CONTINUE
      I=LCH
      DO 40 J=1,NCITY
35    CONTINUE
      IF(TRAFIC(J).GE.ALIM(I+1)) GO TO 39
      TRWP(J)=WPT(I+1)
      GO TO 40
39    I=I+1
      IF(I.GT.NWP) I=1
      IF(I.NE.LCH) GO TO 35
      JSAV=J
      GO TO 41
40    CONTINUE
      RETURN
41    DO 42 J=JSAV,NCITY
42    TRWP(J)=WPT(LCH+1)
      RETURN
      END
```

Figure A.31 ALOKAT Subroutine Listing

```
      SUBROUTINE CDDATA(ALT,NAC,ICD,TIME,DIST,FUEL,ACID)
C     CLIMB,DESCENT DATA ROUTINE
C     ALT-ALTITUDE,NAC-A/C INDEX,ICD-0=READ,1=CLIMB,2=DESCENT
      COMMON RE,PI,IR,IW,ID
      DIMENSION TABLE(4,6,8),ACV(4),CLDS(2,2)
      DATA CLDS/4HCLIM,1HB,4HDESC,3HENT/
C     TABLE(ALT-TIME-DIST-FUEL,ALT,C/D-NAC)
      IF(ICD.GT.0) GO TO 20
C     READ AND WRITE DATA
      READ(ID,101) ACV
101   FORMAT(6X,4A4)
      READ(ID,102) TABLE
102   FORMAT(5X,F7.0,F7.4,F6.2,F6.0)
      IF(ICD.LT.0) RETURN
      WRITE(IW,200)
200   FORMAT(/T2,*CLIMB/DESCENT TABLES*/)
      DO 10 I=1,4
      DO 10 J=1,2
      M=(I-1)*2+J
      WRITE(IW,201) CLDS(1,J),CLDS(2,J),ACV(I)
201   FORMAT(/T2,2A4,*DATA FOR THE *,A4/T5,*ALTITUDE*,T19,*TIME*,
     1T29,*DIST*,T39,*FUEL*/)
      DO 10 L=1,6
      WRITE(IW,202) (TABLE(K,L,M),K=1,4)
202   FORMAT(T18,F10.0,F10.4,F10.2,F10.0)
10    CONTINUE
      RETURN
C     TABLE LOOK-UP
20    M=(NAC-1)*2+ICD
      DO 21 I=2,6
      IS=I
      IF(ALT.LE.TABLE(1,I,M)) GO TO 22
21    CONTINUE
22    DN=ALT-TABLE(1,IS-1,M)
      DD=TABLE(1,IS,M)-TABLE(1,IS-1,M)
      FRAC=DN/DD
      DT=TABLE(2,IS,M)-TABLE(2,IS-1,M)
      DD=TABLE(3,IS,M)-TABLE(3,IS-1,M)
      DF=TABLE(4,IS,M)-TABLE(4,IS-1,M)
      TIME=DT*FRAC+TABLE(2,IS-1,M)
      DIST=DD*FRAC+TABLE(3,IS-1,M)
      FUEL=DF*FRAC+TABLE(4,IS-1,M)
      ACID=ACV(NAC)
      RETURN
      END
```

Figure A.32 CDDATA Subroutine Listing

```
      SUBROUTINE CRDATA(ALT,NAC,ICD,DELT,DELF,ACID)
C     CRUISE DATA ROUTINE
C     ALT-ALTITUDE,NAC-A/C INDEX,ICD-O=READ,1=CLIMB,2=DESCENT
C     DELT-TIME PENALTY,DELF-FUEL PENALTY,ACID-A/C IDENT
      COMMON RE,PI,IR,IW,ID
      DIMENSION TABLE(3,6,8),ACV(4),CLDS(2,2)
      DATA CLDS/4HCLIM,1HB,4HDESC,3HENT/
C     TABLE(ALT-DELT-DELB,ALT,C/D-NAC)
      IF(ICD.GT.O) GO TO 20
C     READ AND WRITE DATA
      READ(ID,101) ACV
101   FORMAT(6X,4A4)
      READ(ID,102) TABLE
102   FORMAT(5X,F7.0,F9.6,F7.3)
      IF(ICD.LT.O) RETURN
      WRITE(IW,200)
200   FORMAT(/T2,*CRUISE PENALTY TABLES*/)
      DO 10 I=1,4
      DO 10 J=1,2
      M=(I-1)*2+J
      WRITE(IW,201) CLDS(1,J),CLDS(2,J),ACV(I)
201   FORMAT(/T2,2A4,*DATA FOR THE *,A4/T5,*ALTITUDE*,
     1T17,*D-TIME*,T27,*D-FUEL*/)
      DO 10 L=1,6
      WRITE(IW,202) (TABLE(K,L,M),K=1,3)
202   FORMAT(T2,F10.0,F10.3,F10.3)
10    CONTINUE
      RETURN
C     TABLE LOOK-UP
20    M=(NAC-1)*2+ICD
      DO 21 I=2,6
      IS=I
      IF(ALT.LE.TABLE(1,I,M)) GO TO 22
21    CONTINUE
22    DN=ALT-TABLE(1,IS-1,M)
      DD=TABLE(1,IS,M)-TABLE(1,IS-1,M)
      FRAC=DN/DD
      DT=TABLE(2,IS,M)-TABLE(2,IS-1,M)
      DF=TABLE(3,IS,M)-TABLE(3,IS-1,M)
      DELT=DT*FRAC+TABLE(2,IS-1,M)
      DELF=DF*FRAC+TABLE(3,IS-1,M)
      ACID=ACV(NAC)
      RETURN
      END
```

Figure A.33 CRDATA Subroutine Listing

```
      SUBROUTINE RDELD(TRAFIC,ATRWP,NTR,NCITY,RAD,DEL)
      DIMENSION TRAFIC(200),ATRWP(200),NTR(200)
      DEL=0.
      DO 10 I=1,NCITY
      AI=TRAFIC(I)-ATRWP(I)
      AI=AI*.0174532925
10    DEL=DEL+NTR(I)*RAD*(1.-COS(AI))
      RETURN
      END
```

Figure A.34 RDELD Subroutine Listing

```
      SUBROUTINE LLRAB(AA,OA,AB,OB,RAB,BAB)
      COMMON RE,PI,IR,IW,ID
      SLA=SIN(AA)
      CLA=SQRT(1.-SLA*SLA)
      SLB=SIN(AB)
      CLB=SQRT(1.-SLB*SLB)
      SDLT2=SIN((AB-AA)/2.)
      SDLN2=SIN((OB-OA)/2.)
      CDLN2=SQRT(1.-SDLN2*SDLN2)
      SDLN=2.*SDLN2*CDLN2
      SSB2=CLA*CLB*SDLN2*SDLN2+SDLT2*SDLT2
      IF(SSB2.LT.0.) SSB2=0.
      SB2=SQRT(SSB2)
      SCB2=1.-SSB2
      IF(SCB2.LT.0.) SCB2=0.
      CB2=SQRT(SCB2)
      IF(CB2) 10,10,5
5     B2=ATAN(SB2/CB2)
      GO TO 15
10    B2=PI/2.
15    RAB=2.*RE*B2
      CB=1.-2.*SSB2
      IF(CLA) 22,22,19
19    CBAB=(SLB-SLA*CB)/CLA
      SBAB=CLB*SDLN
      BAB=ANGLE(ATAN2(SBAB,CBAB))
      RETURN
22    BAB=PI
      IF(SLA.LT.0.) BAB=2.*PI
      RETURN
      END
```

Figure A.35 LLRAB Subroutine Listing

```
      FUNCTION ANGLE(THETA)
      COMMON RE,PI,IR,IW,ID
      TWOPI=2.*PI
      THETA1=AMOD(THETA,TWOPI)
      IF(THETA1.LT.0.) THETA1=THETA1+TWOPI
      ANGLE=THETA1
      RETURN
      END
```

Figure A.36 ANGLE Function Listing

were evaluated used the same arrival and departure runways. The TACOMP procedure was used to compare RNAV and VOR-radar vector terminal route structures. If the traffic levels or the aircraft identification in the input data do not correspond, then an error message is printed on the ouput file to indicate that an invalid comparison was made. A diagram of the major input, processing and output features of TACOMP is shown in Figure A.37.

A.5.2 Input Data

Three input data files are used by TACOMP. These files are TAPE1, TAPE2 and TAPE4. TAPE1 and TAPE2 each contain ouput from the TEVALP program. The data content and format are contained in Section A.4.3 in the TAPE2 output description. The program is set up such that a positive output indicates that the route structures in TAPE2 compare favorably with those in TAPE1. A negative output means that the opposite is true.

The input data that is contained in TAPE4 is aircraft performance data. These data represent cruise altitude time and fuel consumption rates in terms of minutes/nm and pounds/nm. The time rate is the reciprocal of the cruise groundspeed and the fuel rate is the reciprocal of the cruise specific range. The file contains data for four aircraft. These aircraft should be the same four that are used in the TEVALP analysis. The file contains 8 records, 4 for arrivals followed by 4 for departures. Each record is as follows:

Characters	NAME	FORMAT	DESCRIPTION
1-4	TABLE(1,I)	A10	aircraft identification
5-10			blank
11-20	TABLE(2,I)	F10.4	time rate (min/nm)
21-30	TABLE(3.I)	F10.2	fuel rate (lb/nm)

An example of a TAPE4 file is shown in Figure A.38. Different time and fuel rates are used for arrivals and departures to account for differences in aircraft weights and desired cruise altitudes.

A.5.3 Output Data

The output of TACOMP is a file, TAPE3, that is intended for line printer output. An example output is shown in Figure A.39. On the first line of output is written the identification of the two runs and the dates that the TEVALP analysis was performed. This is followed by a line that identifies the following data to be "ARRIVAL DATA". If the traffic samples of the route structures are not identical, a message is written on the file. Next the comparison of traffic weighted route lengths is written followed by the comparison of traffic weighted misalignment distance. If there exists a mismatch between aircraft in the two input files and in the aircraft performance tables, an error message is written on the ouput file. The following four lines of output contain the aircraft identification with the time benefit and fuel benefit for that aircraft. Then, the departure data is written in the same manner as the arrival data. Finally, the average time and fuel benefit for each aircraft is written as the last output to the TAPE3 file.

PROGRAM TACOMP

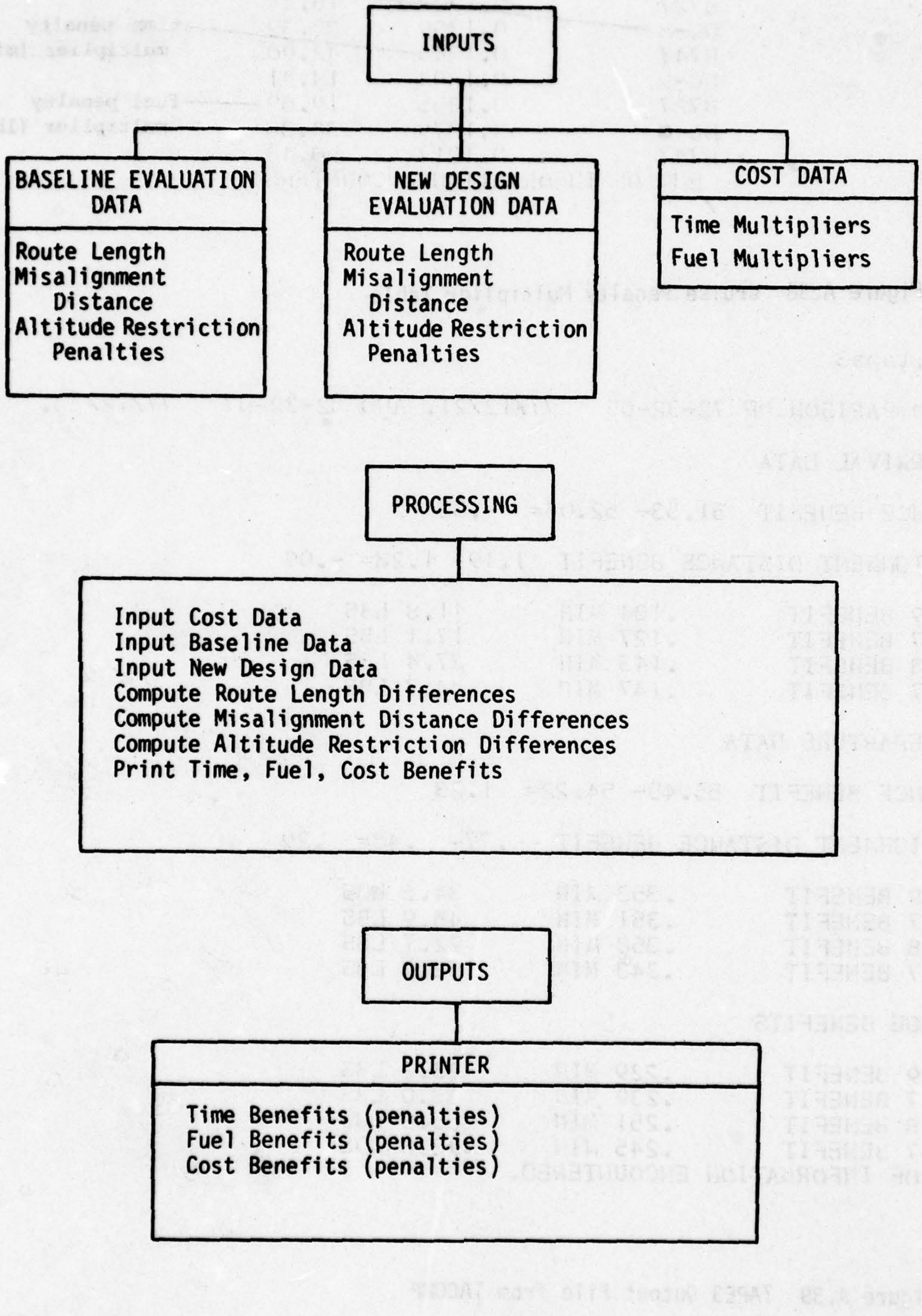


Figure A.37 TACOMP Program Functional Diagram

```
copy,tape4
DC-9          0.1351     11.14
B727          0.1302     16.48
DC-8          0.1309     22.39
B747          0.1245     42.90
DC-9          0.1304     14.41
B727          0.1255     19.59
DC-8          0.1279     30.38
B747          0.1217     50.48
 END OF INFORMATION ENCOUNTERED.
/
```

aircraft type

time penalty multiplier (min/nm)

fuel penalty multiplier (lb/nm)

Figure A.38 Cruise Penalty Multiplier Table

```
copy,tape3

    COMPARISON OF 72-32-05   77/12/21. AND 32-32-07   77/12/20.

    ARRIVAL DATA

 DISTANCE BENEFIT   51.53- 52.06=  -.53

 MISALIGNMENT DISTANCE BENEFIT   1.19- 1.28= -.09

   DC-9 BENEFIT          .104 MIN       11.8 LBS
   B727 BENEFIT          .127 MIN       17.1 LBS
   DC-8 BENEFIT          .143 MIN       37.4 LBS
   B747 BENEFIT          .147 MIN       44.7 LBS

    DEPARTURE DATA

 DISTANCE BENEFIT   55.45- 54.22=  1.23

 MISALIGNMENT DISTANCE BENEFIT    .77-   .48=  .29

   DC-9 BENEFIT          .353 MIN       34.6 LBS
   B727 BENEFIT          .351 MIN       48.9 LBS
   DC-8 BENEFIT          .358 MIN       92.7 LBS
   B747 BENEFIT          .343 MIN      152.8 LBS

 AVERAGE BENEFITS

   DC-9 BENEFIT          .229 MIN       23.2 LBS
   B727 BENEFIT          .239 MIN       33.0 LBS
   DC-8 BENEFIT          .251 MIN       65.0 LBS
   B747 BENEFIT          .245 MIN       93.8 LBS
 END OF INFORMATION ENCOUNTERED.
/
```

Figure A.39 TAPE3 Output File from TACOMP

A.5.4 Program Description

The processing in the TACOMP program is very straightforward. A detailed flow diagram of the program is shown in Figure A.40. The first part of the program is used to initialize the data set reference unit numbers and to set the arrival-departure switch value IAD to 1. Then the performance data is read from TAPE4 and put in the TABLE array. Next the route structure identification and evaluation dates are read from files TAPE1 and TAPE2. At 10 the processing of the arrival data begins. The traffic weighted route lengths and traffic data are read from the two input files. A comparison is made of the traffic levels (ITRA1.NE.ITRA2). If a mismatch occurs, an error message is written and then processing continues. The route length difference DIST is computed and this data is sent to the output file. Then the misalignment distance data is read from TAPE1 and TAPE2 and the difference DEL is computed. This data is then written on TAPE3. The total terminal distance benefit DBEN is computed as the sum of the route length and misalignment distance benefits. Then a DO loop is entered where the DO index I corresponds to the four aircraft types. An index value M is computed which permits the appropriate values in the performance data tables to be accessed. Next the aircraft identification data, time penalties and fuel penalties are read from TAPE1 and TAPE2. The aircraft identifiers are checked and an error message is printed if there is a difference in the identification data. Finally the time and fuel benefits, TIME and FUEL, are computed and stored in the SAVE array. The time and fuel benefits plus the aircraft identification are sent to the output file. The DO index is incremented and processing for the next aircraft type begins.

Once all four aircraft benefits have been computed, program control is shifted to 50 where the arrival-departure switch is incremented by 1. If IAD is not equal to 3, the "DEPARTURE DATA" message is written and control jumps back to 10 where the departure benefits are computed in exactly the same manner as the arrival data. If IAD equals 3, then both departures and arrivals have been evaluated. Program control jumps to 60 where the average benefit values are computed in a DO loop using the data in the SAVE array. This data is written on the output file, TAPE3. When the fourth aircraft has been processed. program control jumps to 70 where execution is halted on a STOP instruction.

A.5.5 Program Listing

A listing of the TACOMP program is shown in Figure A.41.

A.6 PROGRAM TROPT

A.6.1 Purpose of Program

The TROPT program is used to determine candidate boundary waypoint locations for the terminal area. These waypoint locations are found by a procedure which minimizes the misalignment distance value of a terminal area. In order to perform the minimization, a traffic sample describing the terminal area traffic demand is required. In addition, some basic terminal area configuration data is required. This data concerns the number of arrival and departure sectors that

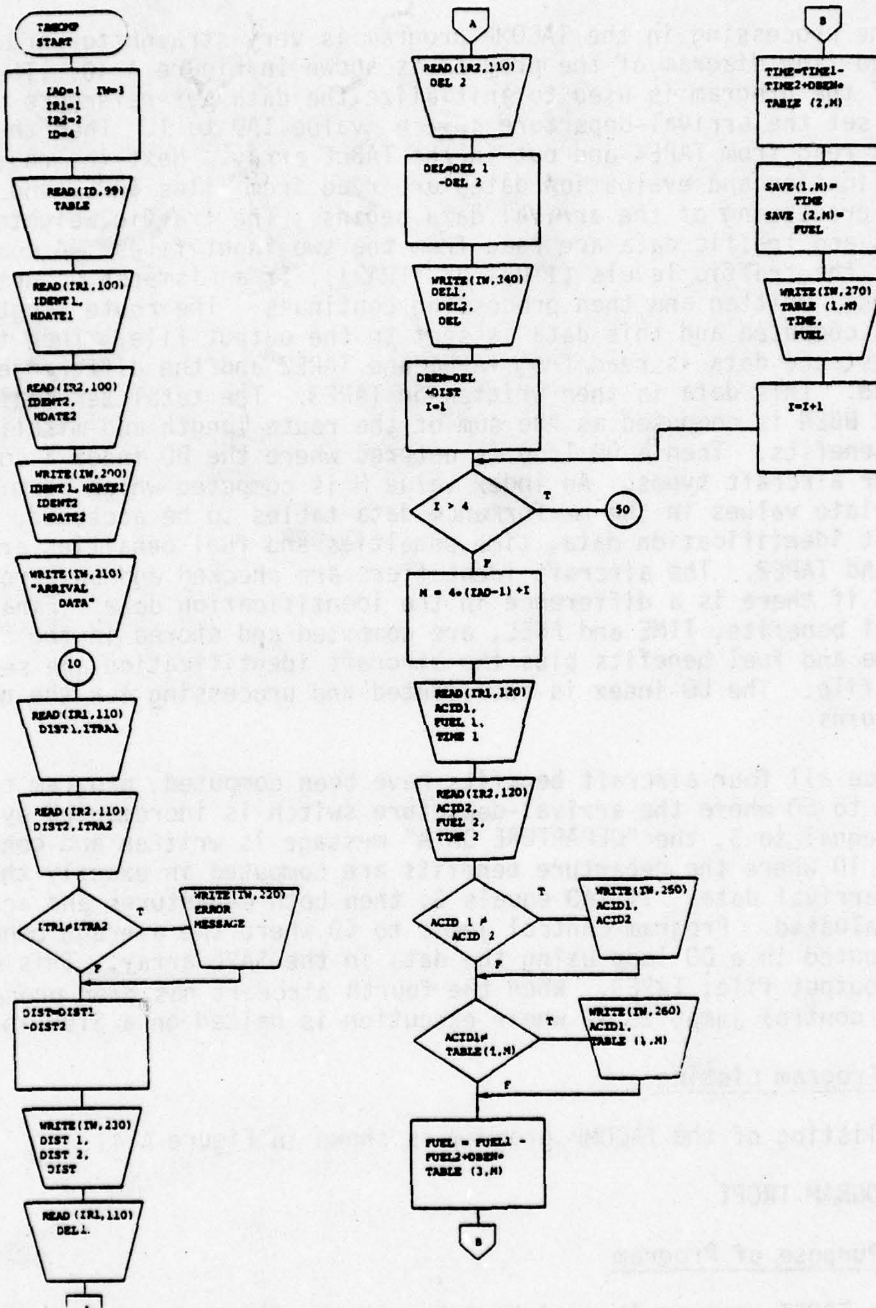


Figure A.40 TACOMP Program Flow Diagram (Pg. 1 of 2)

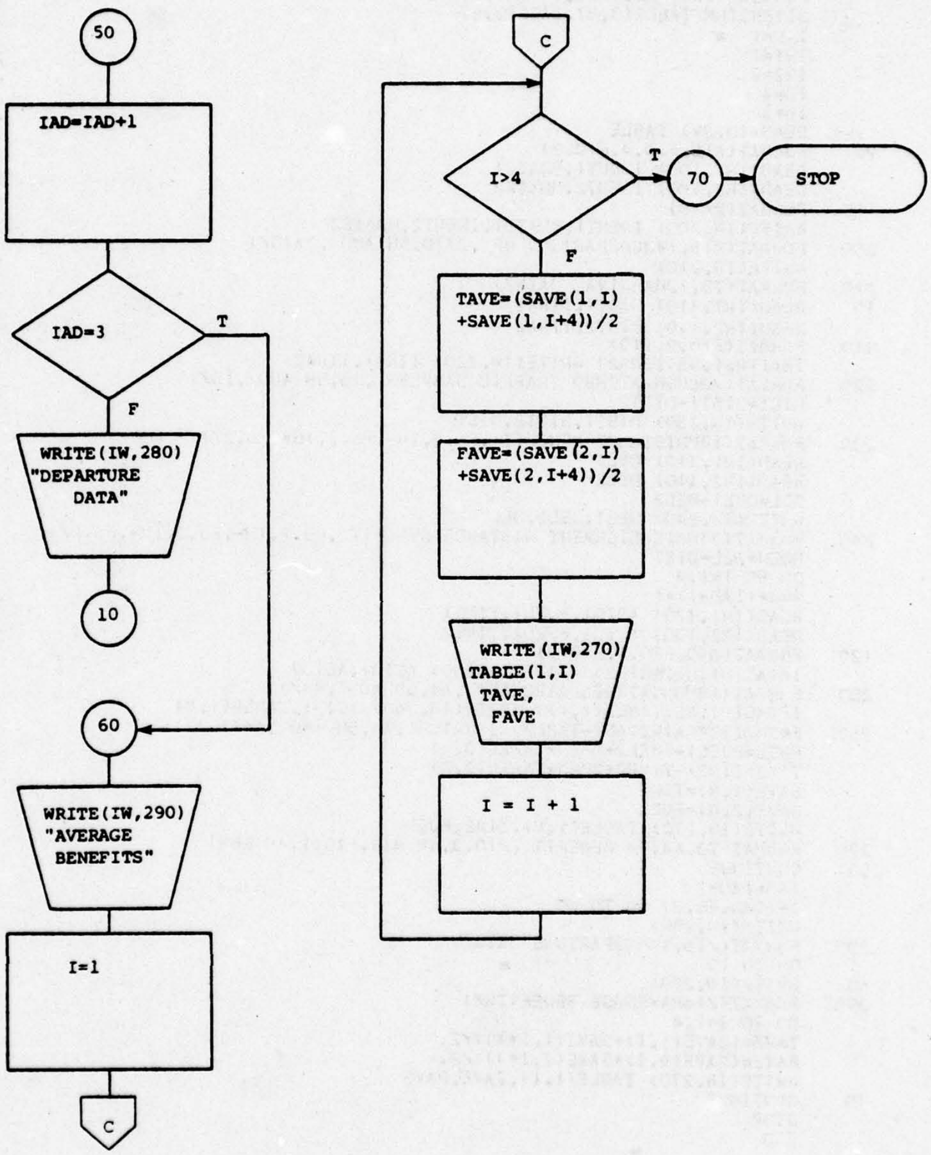


Figure A.40 TACOMP Program Flow Diagram (Pg.2 of 2)

```
      PROGRAM TACOMP(TAPE1,TAPE2,TAPE3,TAPE4)
      DIMENSION TABLE(3,8),SAVE(2,8)
      IAD=1
      IR1=1
      IR2=2
      ID=4
      IW=3
      READ(ID,99) TABLE
99    FORMAT(A10,F10.4,F10.2)
      READ(IR1,100) IDENT1,HDATE1
      READ(IR2,100) IDENT2,HDATE2
100   FORMAT(2A10)
      WRITE(IW,200) IDENT1,HDATE1,IDENT2,HDATE2
200   FORMAT(/T5,14HCOMPARISON OF ,2A10,5H AND ,2A10/)
      WRITE(IW,210)
210   FORMAT(T5,12HARRIVAL DATA/)
10    READ(IR1,110) DIST1,ITRA1
      READ(IR2,110) DIST2,ITRA2
110   FORMAT(F10.2,I10)
      IF(ITRA1.NE.ITRA2) WRITE(IW,220) ITRA1,ITRA2
220   FORMAT(/26HUNMATCHED TRAFFIC SAMPLES ,I5,5H AND ,I5/)
      DIST=DIST1-DIST2
      WRITE(IW,230) DIST1,DIST2,DIST
230   FORMAT(17HDISTANCE BENEFIT ,F6.2,1H-,F6.2,1H=,F6.2/)
      READ(IR1,110) DEL1
      READ(IR2,110) DEL2
      DEL=DEL1-DEL2
      WRITE(IW,240) DEL1,DEL2,DEL
240   FORMAT(30HMISALIGNMENT DISTANCE BENEFIT ,F5.2,1H-,F5.2,1H=,F5.2/)
      DBEN=DEL+DIST
      DO 50 I=1,4
      M=4*(IAD-1)+I
      READ(IR1,120) ACID1,FUEL1,TIME1
      READ(IR2,120) ACID2,FUEL2,TIME2
120   FORMAT(A10,F10.1,F10.3)
      IF(ACID1.NE.ACID2) WRITE(IW,250) ACID1,ACID2
250   FORMAT(18HUNMATCHED AIRCRAFT ,A4,5H AND ,A4/)
      IF(ACID1.NE.TABLE(1,M)) WRITE(IW,260) ACID1,TABLE(1,M)
260   FORMAT(24HAIRCRAFT-TABLE MISMATCH ,A4,5H AND ,A4/)
      FUEL=FUEL1-FUEL2+DBEN*TABLE(3,M)
      TIME=TIME1-TIME2+DBEN*TABLE(2,M)
      SAVE(1,M)=TIME
      SAVE(2,M)=FUEL
      WRITE(IW,270) TABLE(1,M),TIME,FUEL
270   FORMAT(T3,A4,9H BENEFIT ,F10.3,4H MIN,F10.1,4H LBS)
50    CONTINUE
      IAD=IAD+1
      IF(IAD.EQ.3) GO TO 60
      WRITE(IW,280)
280   FORMAT(/T5,14HDEPARTURE DATA/)
      GO TO 10
60    WRITE(IW,290)
290   FORMAT(/16HAVERAGE BENEFITS/)
      DO 70 I=1,4
      TAVE=(SAVE(1,I)+SAVE(1,I+4))/2.
      FAVE=(SAVE(2,I)+SAVE(2,I+4))/2.
      WRITE(IW,270) TABLE(1,I),TAVE,FAVE
70    CONTINUE
      STOP
      END
```

Figure A.41 TACOMP Program Listing

will be used in the design, the number of waypoints per sector, the terminal radius value, an initial alignment angle increment and the initial angular sector step size. A diagram of the major input, processing and output elements of the TROPT program are shown in Figure A.42.

A.6.2 Input Data

The input data required by the TROPT program are traffic data, read from the TAPE1 file, and terminal configuration data, read from the user's terminal. The traffic data is identical to the traffic data for the TEVALP program described in Section A.4.2 for the TAPE5 file.

The parameters that are read from the terminal are:

NSEG - the number of sectors in the terminal design including both arrivals and departures (NSEG should be an even number)

NP - number of waypoints per sector

RAD - terminal area radius (nm)

BINCR - increment by which the alignment angle of the terminal area is changed at the beginning of each optimization run

STEP - angular step size used in the initial movement of the terminal area sectors

These data are read in free format with the data separated by commas or blanks.

A.6.3 Output Data (See Figure 43)

Data from TROPT is sent directly to the output device through the PRINT instruction. The angular step size by which the sectors are changed is reduced from its initial size to a value less than 1 degree. After the minimization has occurred at each step size, the misalignment distance value is printed along with the initial alignment angle of the terminal sectors and the step size. After the step size has been reduced to less than one degree, the minimum misalignment distance and the initial alignment angle are printed. Once all of the initial alignment angles have been processed, the minimum misalignment distance for all cases is printed along with the angular sector boundary values (SSA) and the nominal arrival and departure waypoint bearings with respect to the terminal area center (SAWP and SDWP). Finally, the terminal area traffic sample is listed along with the nominal arrival and departure waypoint bearings.

A.6.4 Program Description

A.6.4.1 Main Program

A detailed flow diagram of TROPT is shown in Figure A.44. The beginning of the TROPT program is used to read traffic data from the TAPE1 file. The data read is IGARB, which is ignored, TRAFIC(I), which contains the bearing of the origin or destination city, and NTR(I) which contains the number of arrival or departure

PROGRAM TROPT

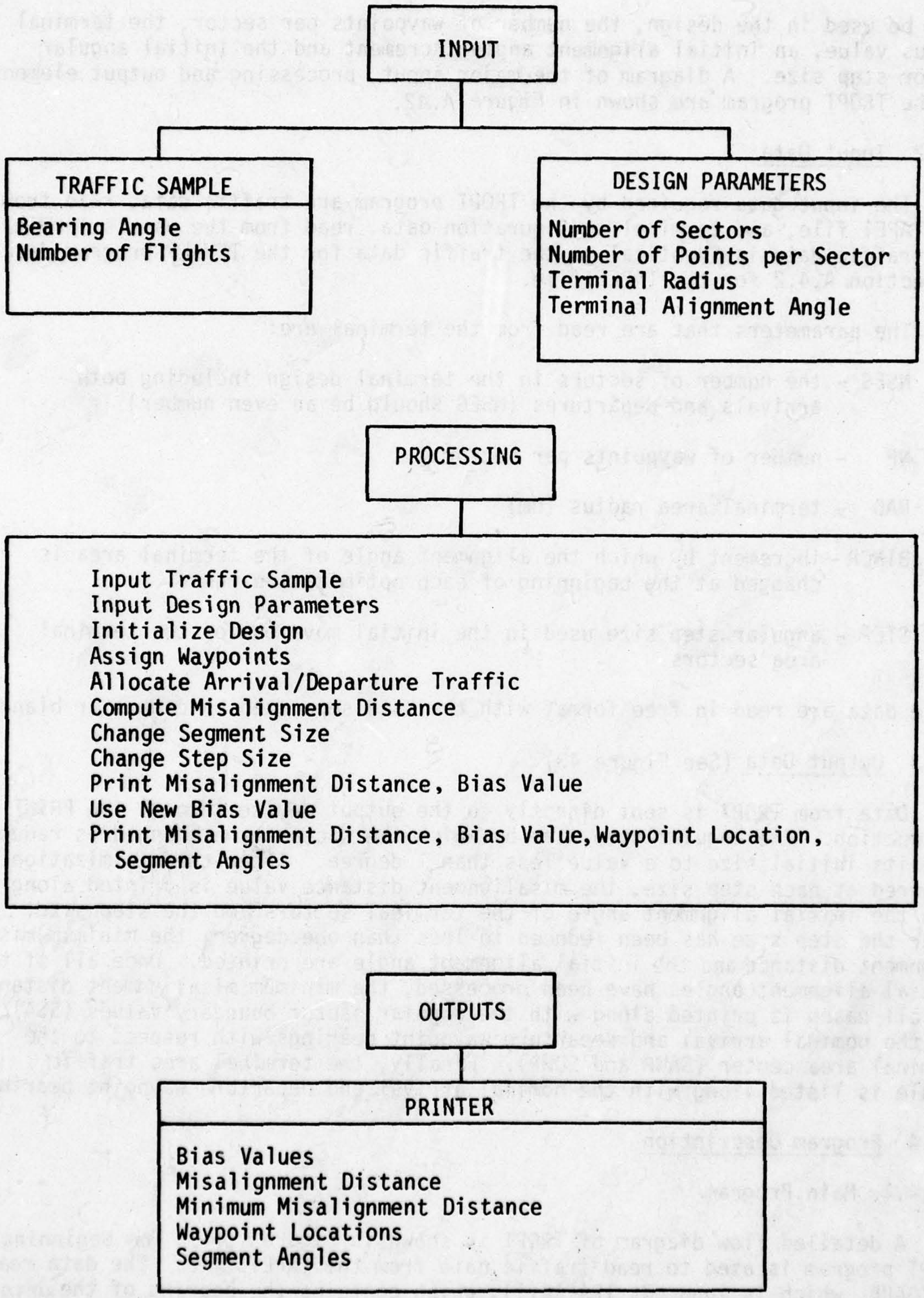


Figure A.42 TROPT Program Functional Diagram

number of terminal segments
number of waypoints per segment
terminal radius value (nm)
alignment angle increment (degrees)
initial step size (degrees)

```
otropt
? 10,2,45.,35.,8.
349.3   0.0   8.0
292.4   0.0   8.0
277.1   0.0   8.0
277.0   0.0   8.0
277.0   0.0   8.0
250.7   0.0   4.0
250.0   0.0   4.0
250.0   0.0   4.0
250.0   0.0   4.0
250.0   0.0   4.0
245.4   0.0   2.0
244.8   0.0   2.0
244.7   0.0   2.0
244.7   0.0   2.0
244.6   0.0   2.0
244.6   0.0   2.0
244.6   0.0   2.0
244.6   0.0   2.0
244.6   0.0   2.0
243.6   0.0   1.0
243.6   0.0   1.0
243.6   0.0
358.9  35.0   8.0
297.9  35.0   8.0
278.1  35.0   8.0
275.8  35.0   8.0
275.8  35.0   8.0
251.3  35.0   4.0
249.7  35.0   4.0
249.7  35.0   4.0
243.3  35.0   2.0
243.3  35.0   2.0
241.6  35.0   1.0
241.6  35.0   1.0
241.6  35.0
```

misalignment distance
initial alignment angle (degrees)
step size (degrees)
minimum misalignment distance for 0° initial alignment angle
minimum misalignment distance for 35° initial alignment angle

```
   MINIMUM MISALIGNMENT DISTANCE VALUE =     241.64

    SEGMENT ANGLES
 50.0   71.0  104.0  175.0  203.0  231.0  266.0  287.0  308.0   23.0

    ARRIVAL(DEPARTURE) WAYPOINT BEARINGS
 55.2   65.8  121.8  157.3  210.0  224.0  271.3  281.8  327.0    5.0

    DEPARTURE(ARRIVAL) WAYPOINT BEARINGS
 79.2   95.7  182.0  196.0  239.8  257.3  292.3  302.8   30.5   43.5
```

CITY BEARING	NO. OF FLIGHTS	ARR WPT BEARING	DEP-WPT BEARING
20.20	4	5.00	30.50
45.70	5	55.25	43.50
50.70	25	55.25	43.50
57.90	3	55.25	43.50
157.30	3	157.25	182.00
186.90	1	210.00	182.00
194.50	5	210.00	196.00
198.00	4	210.00	196.00
198.20	7	210.00	196.00
198.50	1	210.00	196.00
200.10	2	210.00	196.00
205.70	2	210.00	196.00
209.10	5	210.00	196.00
211.20	1	210.00	196.00
215.00	3	210.00	196.00
216.10	1	210.00	196.00
225.90	3	224.00	239.75
232.00	1	224.00	239.75
232.60	12	224.00	239.75
235.80	2	224.00	239.75
245.10	1	224.00	239.75
251.10	3	271.25	257.25
252.20	1	271.25	257.25
255.10	4	271.25	257.25
266.60	1	271.25	257.25
269.30	3	271.25	257.25
269.40	1	271.25	257.25
272.60	1	271.25	257.25
273.70	3	271.25	257.25
274.10	1	271.25	257.25
274.10	3	271.25	257.25
279.30	3	281.75	292.25
280.80	21	281.75	292.25
282.00	1	281.75	292.25
286.50	13	281.75	292.25
289.10	6	281.75	292.25
292.10	1	281.75	292.25
293.60	7	281.75	292.25
296.60	2	281.75	292.25
302.30	2	281.75	302.75
320.70	3	327.00	302.75
320.70	1	327.00	302.75
331.50	2	327.00	302.75
349.10	2	5.00	30.50

```
? stop
 *TERMINATED*
```

Figure A.43 TROPT Program Output

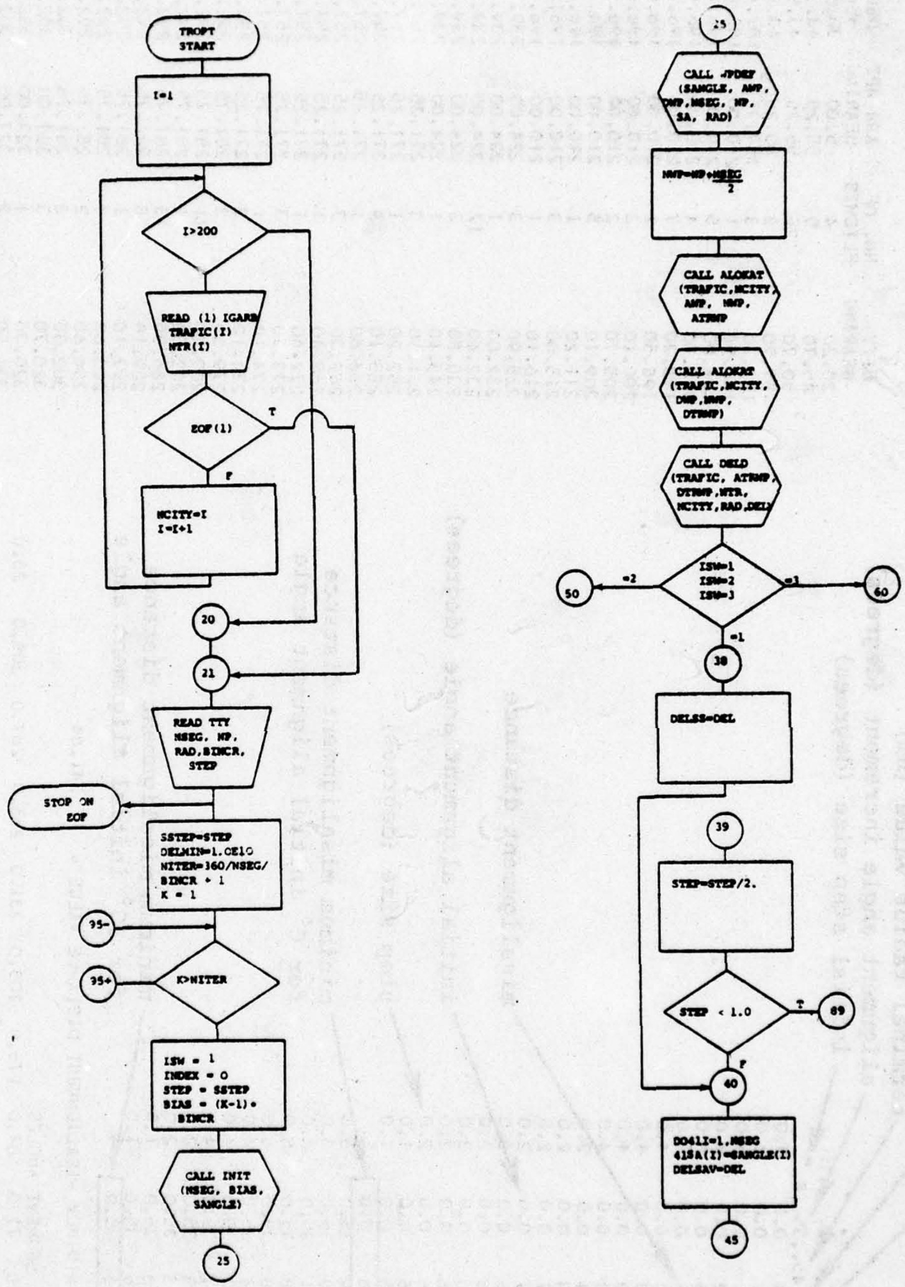


Figure A.44 TROPT Program Flow Diagram (Pg. 1 of 2)

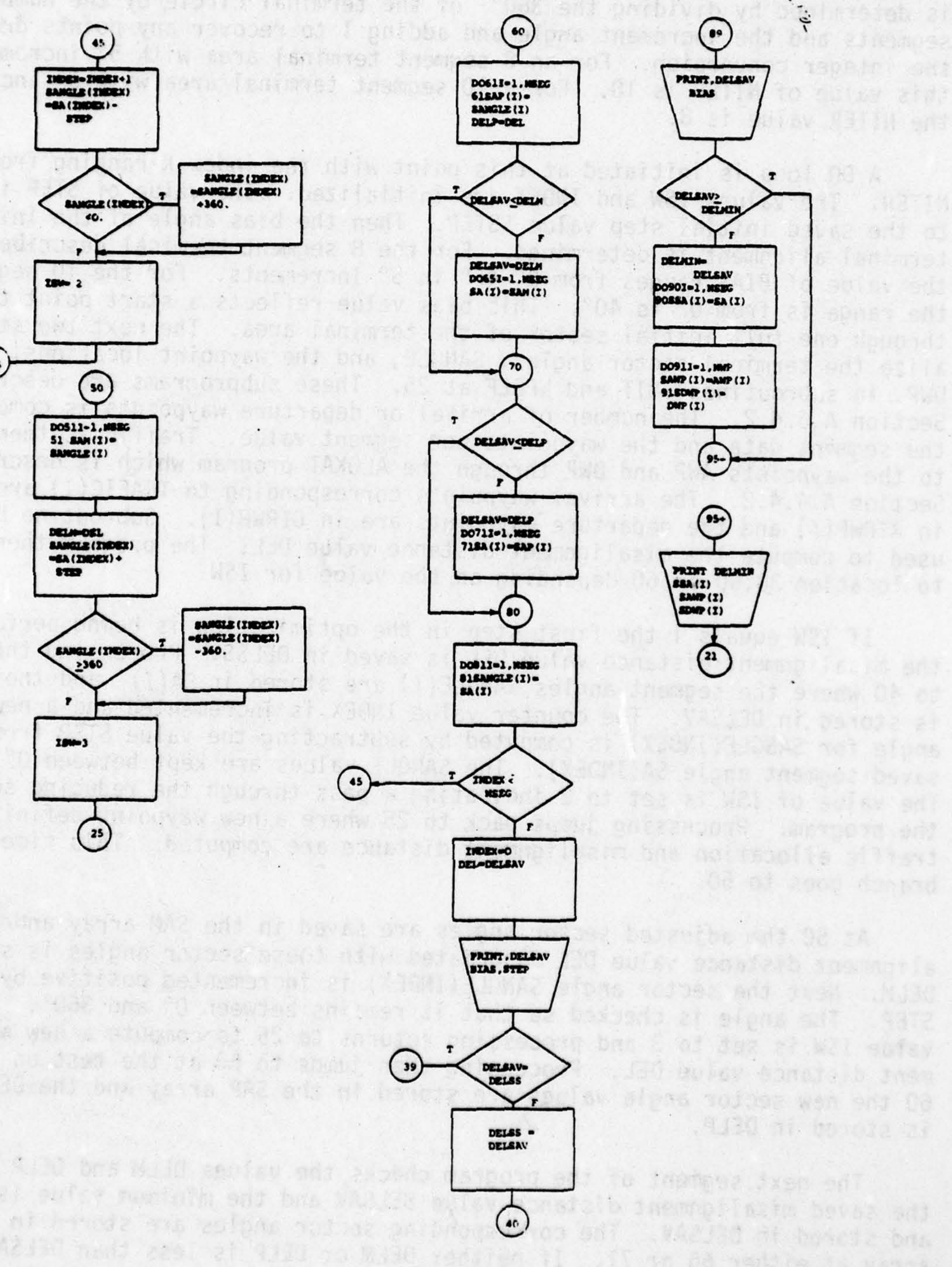


Figure A.44 TROPT Program Flow Diagram (Pg. 2 of 2)

flights per day with the city. The number of cities is stored in NCITY. When an end of file is reached in TAPE1,then program control jumps to 21 where the terminal description data is read from the user's terminal. The initial step size is saved in SSTEP for later use. The parameter DELMIN, which is the misalignment distance, is initialized to a large value in order to start the minimization process. Next the number of iterations, or variations, in the initial terminal alignment angle is determined and stored in NITER. This value is determined by dividing the 360° of the terminal circle by the number of segments and the increment angle and adding 1 to recover any points dropped by the integer conversion. For an 8 segment terminal area with 5° increments this value of NITER is 10. For a 10 segment terminal area with 5° increments the NITER value is 8.

A DO loop is initiated at this point with the index K ranging from 1 to NITER. The values ISW and INDEX are initialized. The value of STEP is set to the saved initial step value SSTEP. Then the bias angle of the initial terminal alignment is determined. For the 8 segment terminal described previously, the value of BIAS ranges from 0°-45° in 5° increments. For the 10 segment terminal the range is from 0° to 40°. This bias value reflects a start point that ranges through one full initial sector of the terminal area. The next two steps initialize the terminal sector angles, SANGLE, and the waypoint locations, AWP and DWP, in subroutines INIT and WPDEF at 25. These subprograms are described in Section A.6.4.2. The number of arrival or departure waypoints is computed from the segment data and the waypoints per segment value. Traffic is then allocated to the waypoints AWP and DWP through the ALOKAT program which is described in Section A.4.4.2. The arrival waypoints corresponding to TRAFIC(I) are stored in ATRWP(I) and the departure waypoints are in DTRWP(I). Subroutine DELD is used to compute the misalignment distance value DEL. The program then branches to location 38,50 or 60 depending on the value for ISW.

If ISW equals 1 the first step in the optimization is being performed and the misalignment distance value DEL is saved in DELSS. Processing then jumps to 40 where the segment angles SANGLE(I) are stored in SA(I) and the value DEL is stored in DELSAV. The counter value INDEX is incremented and a new segment angle for SANGLE(INDEX) is computed by subtracting the value STEP from the saved segment angle SA(INDEX). The SANGLE values are kept between 0° and 360°. The value of ISW is set to 2 indicating a pass through the reducing section of the program. Processing jumps back to 25 where a new waypoint definition, traffic allocation and misalignment distance are computed. This time the ISW branch goes to 50.

At 50 the adjusted sector angles are saved in the SAM array and the misalignment distance value DEL associated with these sector angles is saved in DELM. Next the sector angle SANGLE(INDEX) is incremented positive by an amount STEP. The angle is checked so that it remains between 0° and 360°. The switch value ISW is set to 3 and processing returns to 25 to compute a new misalignment distance value DEL. Processing then jumps to 60 at the test on ISW. At 60 the new sector angle values are stored in the SAP array and the DEL value is stored in DELP.

The next segment of the program checks the values DELM and DELP against the saved misalignment distance value DELSAV and the minimum value is chosen and stored in DELSAV. The corresponding sector angles are stored in the SA array at either 65 or 71. If neither DELM or DELP is less than DELSAV, then

the DELSAV and SA values remain unchanged. At 80 the SANGLE array is set equal to the SA array to prepare for the next series of computations. The value of INDEX is checked to see if all sectors have been adjusted both negative and positive (INDEX<LNSEG). If all sectors have not been evaluated, processing returns to 45 where INDEX is incremented and the procedure is repeated. If all sectors have been evaluated, INDEX is reset to zero and the minimum value for the misalignment distance at this point in the processing, DELSAV, is stored in DEL. The values of DELSAV, BIAS and STEP are written on the user's terminal. Next the DELSAV and DELSS values are checked for equality. If they are equal, this means that no reduction in misalignment distance DELSAV has occurred by the adjustment of the sector angles. Thus a minimum value has been found for the specified step size and initial alignment angle. If this minimum has been achieved, then processing goes to 39 where the step size, STEP, is reduced by half. If the step size is less than 1 degree, the minimum value for the specified initial segment angle has been found and the program jumps to 89. If the value of DELSS is not equal to DELSAV, then DELSS is set equal to DELSAV, which is the current minimum value of misalignment distance, and processing goes to 40 where the segment angle adjustment procedure begins again.

At 89 the value of the minimum misalignment distance and the specified terminal alignment angle are printed. The value of DELSAV is then checked against the value of DELMIN, which was initialized to a large value at the start of the program. On the first pass through this step, the test fails and DELMIN is reset to DELSAV and the sector angles which produced this value of DELSAV are stored in the SSA array. Also, the corresponding arrival and departure waypoints are stored in the SAWP and SDWP arrays, respectively. If, on subsequent passes through the DELSAV≥DELMIN test, the test does not fail the processing jumps to 95.

At 95 the value of the DO parameter is incremented by 1 and tested to see if all initial segment angle cases have been processed. If K≤NITER, the entire procedure beginning at the top of the DO 95 loop is repeated. After all NITER cases have been processed, the minimum overall misalignment distance value DELMIN is printed along with the corresponding sector angles, SSA, and waypoint angles, SAWP and SDWP. Processing then returns to 21 where a new terminal configuration may be input from the user's terminal.

A.6.4.2 TROPT Subprograms (See Figures A.45, A.46 and A.47)

The TROPT program uses four subprograms, INIT, WPDEF, ALOKAT and DELD. Subroutine ALOKAT was described in Section A.4.4.2. Subroutine DELD is very similar to RDELD which was also described in Section A.4.4.2. The only difference in the two subroutines is that RDELD is used to calculate misalignment distance for either arrivals or departures but not both, while DELD computes misalignment distance for both arrivals and departures.

The INIT subroutine is used to establish initial sector boundaries given the number of arrival and departure sectors, NSEG, and an initial alignment angle, BIAS. This procedure divides the terminal into NSEG equal sectors by computing an angle ANG which is found by dividing the 360° of the terminal area circle by NSEG. Then a DO loop is used to find the sector angle boundaries. The initial sector angle SANGLE(1) is BIAS. The remaining sector angles are SANGLE(2)=BIAS+ANG, SANGLE(3)=BIAS+2*ANG, etc. The SANGLE values are kept

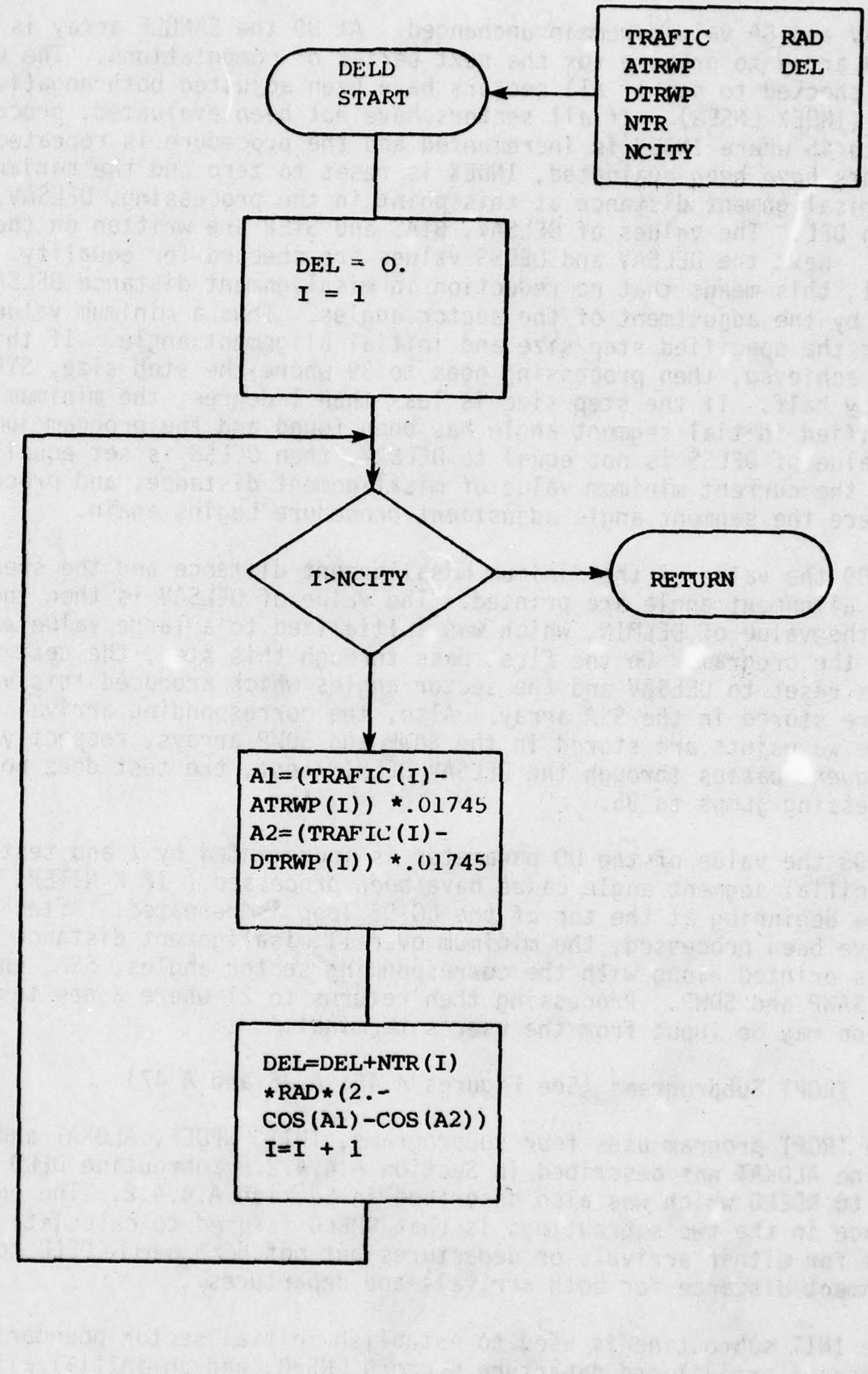


Figure A.45 DELD Subroutine Flow Diagram

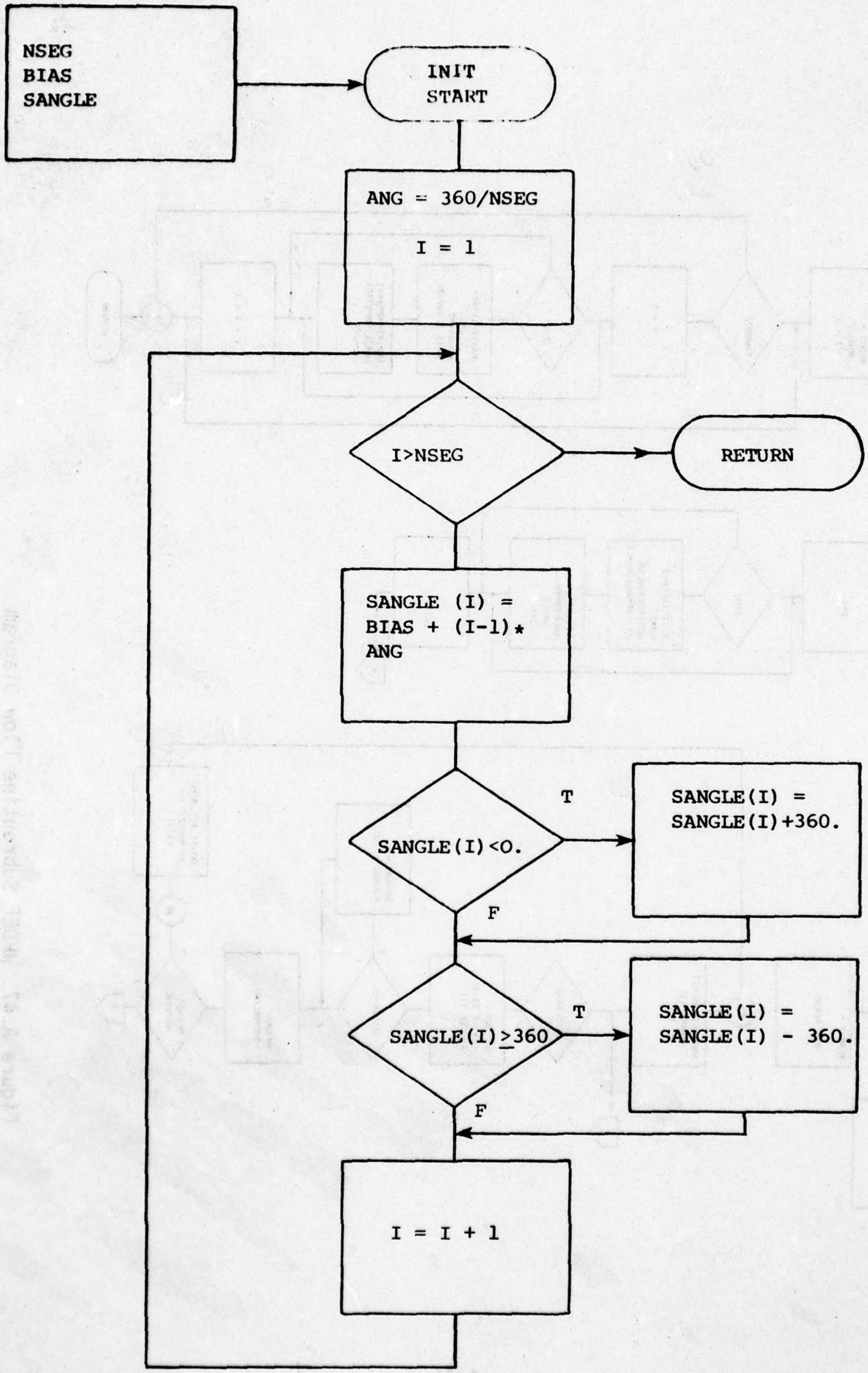


Figure A.46 INIT Subroutine Flow Diagram

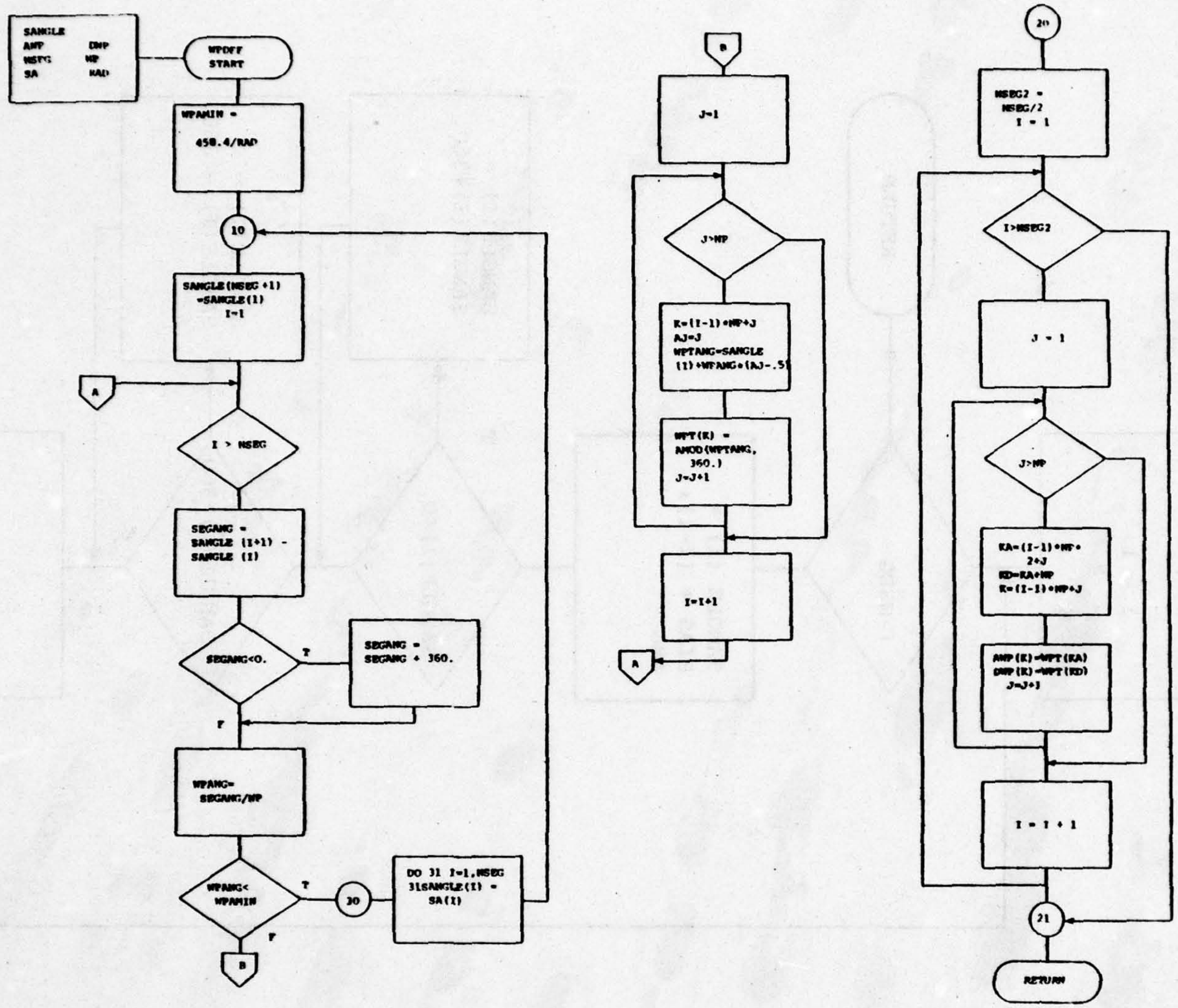


Figure A.47 WPDEF Subroutine Flow Diagram

between 0° and 360° by appropriate test. When all SANGLE values have been assigned, control is returned to the calling program.

The subroutine WPDEF is used to compute waypoint bearing angles with respect to the terminal area center. The arrival waypoint bearings are stored in the AWP array and the departure waypoint bearings are stored in the DWP array. Input data to WPDEF are supplied through the argument list and include the sector angle array SANGLE, the saved sector angle array SA, the number of segments NSEG, the number of waypoints per sector NP, and the terminal radius RAD.

The processing begins by computation of a minimum acceptable waypoint segment angle; that is, a minimum angular distance between waypoints. This computation is based upon an eight mile route width (±4 nm) at the terminal boundary point. This 8 mile route width becomes, in terms of angles:

$$\text{WPAMIN} = 8 \text{ nm} * \frac{180}{\pi} * \frac{1}{\text{RAD}} = \frac{458.4}{\text{RAD}}$$

Next, the NSEG+1 sector angle is set equal to the first sector angle. This procedure provides computational convenience in the DO loops. The procedure then calls for a DO loop through 20 with I as the counter. The segment angle is computed as the difference between two adjacent sectors. This value is checked to determine if SEGANG is negative. If SEGANG is negative, 360° is added to restore the parameter to the appropriate range. The waypoint angle for the segment angle SEGANG is computed by dividing the segment angle SEGANG by the number of waypoints per sector NP. Then the waypoint angle is checked to see if it is less than the minimum acceptable angle WPAMIN. If WPANG is too small, this means that the input values for SANGLE are inappropriate to support the terminal waypoints. Then SANGLE is restored to the saved sector values in SA and the processing returns to 10 where the waypoint assignment procedure is restarted with the restored SANGLE values.

If the waypoint angle WPANG is appropriate, an inner DO loop through 20 is initiated. This loop has J as a counter and runs from J = 1 to NP, the number of waypoints per sector. An index value K is computed from the two DO parameters I and J, and the number of waypoints per sector NP. The waypoint angle WPTANG is computed by spacing it away from the segment angle boundary, SANGLE(I), by an amount 0.5*WPANG, 1.5*WPANG, 2.5*WPANG, etc. This procedure provides that the waypoints in each sector will be spaced by an amount equal to WPANG, which is different for each sector, and will be spaced 0.5*WPANG from the two sector boundaries. The waypoint angles are constrained to lie between 0° and 360° by the AMOD function and then stored in the array WPT(K). The index counter J for the inner DO is incremented by 1 until all waypoints in the sector have been determined. Then the index I of the outer DO is incremented and the next sector is processed. When all sectors have been processed, program control advances past 20.

The number of arrival or departure segments is computed as NSEG2. A double DO loop is then used to allocate the arrival and departure waypoints. The outer loop runs from 1 to NSEG2 while the inner loop goes from 1 to NP. Arrival and departure index values KA and KD are computed and the corresponding index value K for the AWP and DWP arrays is determined. Finally the arrival and departure waypoint bearing values are saved in AWP(K) and DWP(K). When all waypoint bearings have been allocated, the program control returns to the calling program.

A.6.5 Program Listing

Listings of the TROPT program and the DELD, INIT and WPDEF subprograms are shown in Figures A.48-A.51.

A.7 PROGRAM TRSRT

A.7.1 Purpose of Program

The purpose of the TRSRT program is to provide the capability to sort daily traffic data according to arrival or departure time. This program can be used to identify heavy traffic periods for the terminal arrival and departure sectors. The format used for the traffic input data is similar to that found in the "Official Airline Guide, North American Edition". A functional description of the major input, output and processing sections of the program are shown in Figure A.52.

A.7.2 Input Data

Data for the TRSRT program is read from two files, TAPE1 and TAPE2. The TAPE2 file contains up to 30 aircraft identifiers and aircraft descriptions. Each record in the file contains a four character identifier followed by up to 32 characters of descriptive information. Any number of aircraft between 0 and 30 may be used. The identifiers are stored in the IACTYP array and the descriptions are stored in the IACDES array. An example of the TAPE2 input data is shown in Figure A.53.

Input data in the TAPE1 file consists of two records of identification and program control data followed by the traffic sample data. The first record contains the code for the day of the week for which traffic is being analyzed. This variable name is IDOW and it is a one character interger value ranging from 1 to 7. A 1 corresponds to Monday, 2 is Tuesday, etc. The remaining 32 characters in this record are read in 8A4 format and stored in TITLE. These characters generally contain some description of the traffic sample and the airport in question. The second record in the TAPE1 file is read in 3A4 format and is stored in the array IAD. This record should contain either the word ARRIVAL or DEPARTURE starting in column one. This record determines whether the traffic data is considered as arrival data or departure data and controls the format of the READ instruction of the traffic data.

The remaining records in TAPE1 contain traffic sample data. There are two types of traffic records. The first type of record contains city and traffic data. The data in these records is as follows:

Characters	Name	Format	Description
1-20	INAME	5A4	name of the city
21-27	—	—	blank
28-30	ICTY	A3	airport identifier code
31-33	—	—	blank
34-36	NFLT	I3	number of flight records to be read

The second type of record contains data on the specific flights. The format of this data is similar to that found in the North American Edition of the "Official Airline Guide". The data has the following description:

```
      PROGRAM TROPT(INPUT,OUTPUT,TAPE1)
      DIMENSION SANGLE(25),AWP(26),DWP(26)
      DIMENSION TRAFIC(200),ATRWP(200),DTRWP(200),NTR(200)
      DIMENSION  SA(25),SAM(25),SAP(25)
      DIMENSION SSA(25),SAWP(26),SDWP(26)
      READ(1,199)
      DO 20 I=1,200
      READ(1,199) IGARB,TRAFIC(I),NTR(I)
199   FORMAT(I5,F6.1,I3)
      IF(EOF(1)) 21,20
20    NCITY=I
21    READ *,NSEG,NP,RAD,BINCR,STEP
      SSTEP=STEP
      DELMIN=1.0E10
      NITER=360./NSEG/BINCR+1
      NWP=NP*NSEG/2
      DO 95 K=1,NITER
      ISW=1
      INDEX=0
      STEP=SSTEP
      BIAS=(K-1)*BINCR
      CALL INIT(NSEG,BIAS,SANGLE)
25    CALL WPDEF(SANGLE,AWP,DWP,NSEG,NP,SA,RAD)
      CALL ALOKAT(TRAFIC,NCITY,AWP,NWP,ATRWP)
      CALL ALOKAT(TRAFIC,NCITY,DWP,NWP,DTRWP)
      CALL DELD(TRAFIC,ATRWP,DTRWP,NTR,NCITY,RAD,DEL)
200   FORMAT(13F7.1)
      GO TO (38,50,60),ISW
38    DELSS=DEL
      GO TO 40
39    STEP=STEP/2.
      IF(STEP.LT.1.0) GO TO 89
40    CONTINUE
      DO 41 I=1,NSEG
41    SA(I)=SANGLE(I)
      DELSAV=DEL
45    INDEX=INDEX+1
      SANGLE(INDEX)=SA(INDEX)-STEP
      IF(SANGLE(INDEX).LT.0.) SANGLE(INDEX)=SANGLE(INDEX)+360.
      ISW=2
      GO TO 25
50    DO 51 I=1,NSEG
51    SAM(I)=SANGLE(I)
      DELM=DEL
      SANGLE(INDEX)=SA(INDEX)+STEP
      IF(SANGLE(INDEX).GE.360.) SANGLE(INDEX)=SANGLE(INDEX)-360.
      ISW=3
      GO TO 25
60    DO 61 I=1,NSEG
61    SAP(I)=SANGLE(I)
      DELP=DEL
      IF(DELSAV.LE.DELM) GO TO 70
      DELSAV=DELM
      DO 65 I=1,NSEG
65    SA(I)=SAM(I)
70    IF(DELSAV.LE.DELP) GO TO 80
      DELSAV=DELP
      DO 71 I=1,NSEG
71    SA(I)=SAP(I)
80    DO 81 I=1,NSEG
```

Figure A.48 TROPT Program Listing (Page 1 of 2)

```
31    SANGLE(I)=SA(I)
      IF(INDEX.LT.NSEG) GO TO 45
      INDEX=0
      DEL=DELSAV
      PRINT 200,DELSAV,BIAS,STEP
      IF(DELSAV.EQ.DELSS) GO TO 39
      DELSS=DELSAV
      GO TO 40
39    PRINT 200,DELSAV,BIAS
      IF(DELSAV.GE.DELMIN) GO TO 25
      DELMIN=DELSAV
      DO 20 I=1,NSEG
20    SSA(I)=SA(I)
      DO 21 I=1,NWP
      SAWP(I)=AWP(I)
21    SDWP(I)=DWP(I)
25    CONTINUE
      PRINT 210,DELMIN
210   FORMAT(/,T7,*MINIMUM MISALIGNMENT DISTANCE VALUE = *,F10.2)
      PRINT 220
220   FORMAT(/T8,*SEGMENT ANGLES*)
      PRINT 200,(SSA(I),I=1,NSEG)
      PRINT 230
230   FORMAT(/,T8,*ARRIVAL(DEPARTURE) WAYPOINT BEARINGS*)
      PRINT 200,(SAWP(I),I=1,NWP)
      PRINT 240
240   FORMAT(/,T8,*DEPARTURE(ARRIVAL) WAYPOINT BEARINGS*)
      PRINT 200,(SDWP(I),I=1,NWP)
      CALL ALOKAT(TRAFIC,NCITY,SAWP,NWP,ATRWP)
      CALL ALOKAT(TRAFIC,NCITY,SDWP,NWP,DTRWP)
      PRINT 250
250   FORMAT(/T10,*CITY*,T20,*NO. OF*,T30,*ARR-WPT*,T40,*DEP-WPT*,
     1/,T10,*BEARING*,T20,*FLIGHTS*,T30,*BEARING*,T40,*BEARING*)
      PRINT 260,(TRAFIC(I),NTR(I),ATRWP(I),DTRWP(I),I=1,NCITY)
260   FORMAT(3X,F10.2,I10,2F10.2)
      GO TO 21
      END
```

Figure A.48 TROPT Program Listing (Page 2 of 2)

```
      SUBROUTINE DELD(TRAFIC,ATRWP,DTRWP,NTR,NCITY,RAD,DEL)
      DIMENSION TRAFIC(200),ATRWP(200),DTRWP(200),NTR(200)
      DEL=0.
      DO 10 I=1,NCITY
      A1=TRAFIC(I)-ATRWP(I)
      A2=TRAFIC(I)-DTRWP(I)
      A1=A1*.0174532925
      A2=A2*.0174532925
10    DEL=DEL+NTR(I)*RAD*(2.-COS(A1)-COS(A2))
      RETURN
      END
```

Figure A.49 DELD Subroutine Listing

AD-A062 053 SYSTEMS CONTROL INC PALO ALTO CALIF F/G 17/7
RNAV ROUTE DESIGN-TERMINAL AREA DESIGN PROCEDURES AND TRANSITIO--ETC(U)
JAN 78 E D MCCONKEY, A G HALVERSON DOT-FA72WA-3098

UNCLASSIFIED FAA/RD-78/61 NL

3 OF 3
AD
A062053

END
DATE
FILMED
3 -- 79
DDC

```
      SUBROUTINE INIT(NSEG,BIAS,SANGLE)
      DIMENSION SANGLE(25)
      ANG=360./NSEG
      DO 10 I=1,NSEG
      SANGLE(I)=BIAS+(I-1)*ANG
      IF(SANGLE(I).LT.0.) SANGLE(I)=SANGLE(I)+360.
      IF(SANGLE(I).GE.360.) SANGLE(I)=SANGLE(I)-360.
10    CONTINUE
      RETURN
      END
```

Figure A.50 INIT Subroutine Listing

```
      SUBROUTINE WPDEF(SANGLE,AWP,DWP,NSEG,NP,SA,RAD)
      DIMENSION SANGLE(25),AWP(26),DWP(26),WPT(51),SA(25)
      WPAMIN=458.4/RAD
10    CONTINUE
      SANGLE(NSEG+1)=SANGLE(1)
      DO 20 I=1,NSEG
      SEGANG=SANGLE(I+1)-SANGLE(I)
      IF(SEGANG.LT.0.) SEGANG=SEGANG+360.
      WPANG=SEGANG/NP
      IF(WPANG.LT.WPAMIN) GO TO 30
      DO 20 J=1,NP
      K=(I-1)*NP+J
      AJ=J
      WPTANG=SANGLE(I)+WPANG*(AJ-.5)
20    WPT(K)=AMOD(WPTANG,360.)
      NSEG2=NSEG/2
      DO 21 I=1,NSEG2
      DO 21 J=1,NP
      KA=(I-1)*NP*2+J
      KD=KA+NP
      K=(I-1)*NP+J
      AWP(K)=WPT(KA)
21    DWP(K)=WPT(KD)
      RETURN
30    DO 31 I=1,NSEG
31    SANGLE(I)=SA(I)
      GO TO 10
      END
```

Figure A.51 WPDEF Subroutine Listing

PROGRAM TRSRT

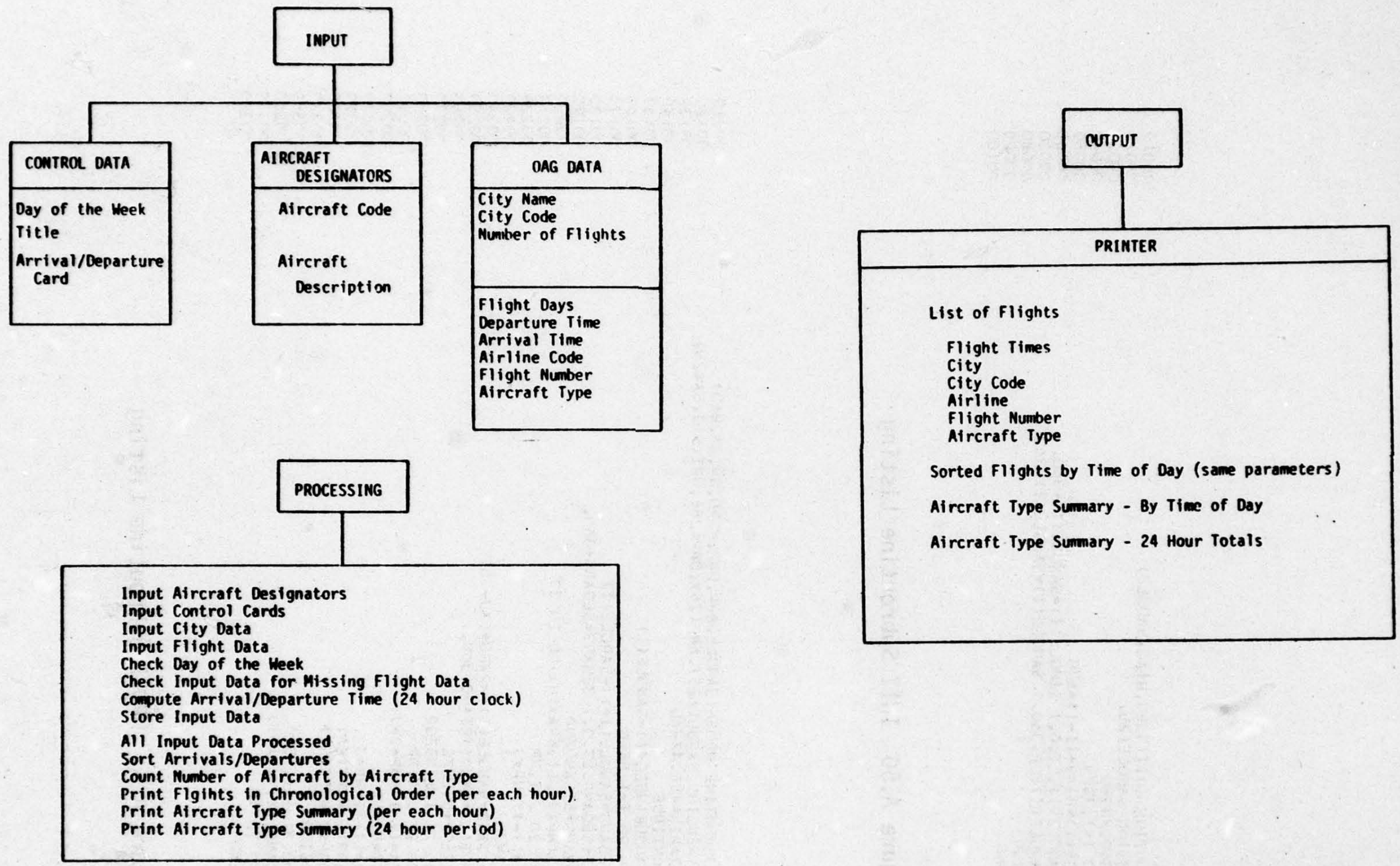


Figure A.52 TRSRT Program Functional Diagram

```
copy,tape2
D9S DC9-30 AND 40
B11 BAC 111 (ALL SERIES)
DC9 DC9-10 AND 20
727 BOEING 727
723 BOEING 727-200
BE9 BEECH 99
707 BOEING 707
D10 DC10 (ALL SERIES)
L10 L1011 (ALL SERIES)
737 BOEING 737
73S BOEING 737-200
747 BOEING 747
END OF INFORMATION ENCOUNTERED.
/
```

aircraft code

aircraft description

Figure A.53 Aircraft Identifier Data for TRSRT

CHARACTERS	NAME	FORMAT	DESCRIPTION
1	ICHAR	A1	X or blank
2-8	IDAY	7I1	numbers 1-7 representing day
9-13	TFLT	F5.2	departure flight time
14	IDN	A1	A-am, P-pm, N-noon, M-midnight
15-16	—	—	blank
17-21	TFLT	F5.2	arrival flight time
22	IDN	A1	A-am, P-pm, N-noon, M-midnight
23-26	—	—	blank
27-28	IAL	A2	airline code
29-32	IFN	I4	airline flight number
33	—	—	blank
34-36	IACTP	A3	three letter aircraft identifier

Most of the input data is self-explanatory except for the first eight characters. This data may be explained with some examples. If column 1 is blank and columns 2, 3 and 4 contain the numbers 1, 3 and 6, this is interpreted as meaning that this flight operated on day 1, Monday, day 3, Wednesday, and day 6, Saturday. If column 1 contained an X and columns 2, 3 and 4 contained a 1, 3 and 6 respectively, this is interpreted as meaning that the flights operated everyday except Monday, Wednesday and Saturday. If the columns are all blank, then the flight operates every day of the week.

In creating the TAPE1 file it is important that the number of flight records following the city record match the NFLT value on the city record. Otherwise a format error will be detected in the READ instruction causing the run to be aborted. An example of the input data in the TAPE1 file is shown in Figure A.54.

A.7.3 Output Data

The output data from the TRSRT program is written on a file called TAPE3 and is intended for line printer output. Two types of output may be written on TAPE3. The first type is that data which results from the nominal operation of the program. The second type of data is error messages that are printed due to some abnormal conditions in the input data. The nominal program output will be described first.

The first record of output is a message identifying the output as being an "ARRIVAL-DEPARTURE DATA SORT..." and printing the day of the week number followed by the title of the sort as contained on the first record of input data from TAPE1. The next lines of output contain reformatted input data that will be sorted by the program. Flights which do not operate on the specified day of the week are deleted from this output list of flights. The scheduled time of the arrival or departure is written along with the name of the city, the airport code, the airline, the flight number and the aircraft type. The flight time is given according to the 24 hour clock based on the local airport time. This output listing is useful for checking and detecting errors in the input data.

Once the traffic data has been sorted by arrival or departure time, the following output is written for each one hour period during the 24 hour sample period. First, a descriptive line is written which identifies the time period, prints whether arrival or departure traffic are being sorted, and writes a header

day of the week

terminal design city

originating city

time zone

city code

number of flights

departure time

arrival time

airline

flight number

type of aircraft

```
copy,tapel
5   INDIANAPOLIS
ARRIVALS
AKRON/CANTON,OH        EDT     CAK     3
          11.48A   11.40A     AL 151 D9S
           4.12P    4.04P     AL 185 D9S
           8.20P    8.14P     AL 447 B11
ATLANTA,GA             EDT     ATL     9
          12.33A   12.47A     EA 462 DC9
          12.36A   12.50A     DL 690 DC9
           9.30A    9.44A     EA 688 727
          10.11A   10.24A     DL 460 725
          12.03P   12.15P     EA 296 DC9
           3.11P    3.33P     EA 264 D9S
           6.14P    6.28P     DL 766 D9S
           7.00P    7.24P     EA 266 D9S
           8.29P    8.42P     DL 438 725
BALTIMORE,MD           EDT     BAL     2
           8.45A    9.13A     AL 225 D9S
           3.26P    3.54P     AL 277 D9S
BLOOMINGTON,IND        EST     BMG     6
           5.55A    6.20A     AL 642 BE9
           7.20A    7.45A     AL 644 BE9
          10.40A   11.05A     AL 646 BE9
           2.00P    2.25P     AL 648 BE9
           3.25P    3.50P     AL 650 BE9
           5.20P    5.45P     AL 652 BE9
BUFFALO,NY             EDT     BUF     2
           9.30A    9.48A     AL 165 D9S
           3.45P    4.06P     AL 437 B11
CHICAGO,ILL            CDT     CHI    11
           6.40A    7.27A     AA 354 725
           8.10A    8.58A     AL 498 B11
           8.40A    9.23A     DL 869 D9S
          10.00A   10.47A     AL 138 D9S
          10.40A   11.29A     AA 238 707
           1.12P    1.55P     DL 359 725
           2.15P    3.02P     AL 194 D9S
           2.25P    3.14P     AA 166 707
           3.45P    4.32P     AL 222 D9S
           4.55P    5.46P     AA 182 B10
           8.10P    8.57P     AL 192 D9S
CINCINNATI,OH          EDT     CVG     5
          10.45A   10.17A     AA 429 725
           5.10P    4.42P     TW 139 707
           5.30P    5.02P     AA 471 725
           9.30P    8.59P     AL 479 B11
           9.55P    9.27P     AA 453 725
COLUMBUS,OH            EDT     CMH     1
           6.15P    5.59P     TW 531 725
DALLAS/FT.WORTH,TX     CDT     DFW     3
           6.50A    8.42A     AA  84 707
           1.05P    3.00P     AA 613 725
           6.55P    8.47P     AA 622 707
DAYTON,OH              EDT     DAY     6
          10.35A   10.09A     TW 129 DC9
          11.55A   11.27A     AL 135 D9S
           4.25P    4.03P     TW 189 L10
           4.34P    4.06P     AL 241 D9S
          10.26P    9.58P     AL 425 B11
          11.30P   11.02P     TW 279 725
 END OF INFORMATION ENCOUNTERED.
/
```

Figure A.54 Traffic Data Input for TRSRT

identifying time, city code, flight number and aircraft type columns in the output. Next the sorted traffic data for the appropriate time period is written. The time, city name, airport code, airline code, flight number and aircraft type code are written on each line in chronological order of arrival or departure. Following this data is an accumulation of the aircraft types which were operated during the specified hour time period. After all hourly data have been written, the total number of aircraft by type for the specified 24 hour period are printed. If any aircraft descriptors have not been included in the TAPE2 input data, an unclassified aircraft column is provided so that these aircraft may be included in the total traffic count. An example of the output data from TRSRT is shown in Figure A.55.

Five types of error messages may be written on the TAPE3 file by the TRSRT program. The first error which may be detected is an error in the arrival or departure record read from TAPE1. If the first four characters on this record are not either ARRI or DEPA, then the error is flagged and the record image is written on TAPE3. The program is aborted after the message is written. The second type of error that may be detected occurs if more than 400 cities are processed. If this occurs then a message indicating this fact is written and program execution continues without processing the remaining cities. Similarily, if more than 500 flights are processed, a message indicating this fact is written on TAPE3 and the remaining flight records are not processed. The fourth type of error that may be detected by TRSRT occurs if an end of file is detected in TAPE1 before all of the flight records specified by the NFLT parameter have been read. A message that a flight card is missing is written on TAPE3 and processing continues. The fifth error message that may be written occurs when an end of file is detected for the arrival or departure specification record in TAPE1. A message indicating this fact is written on TAPE3 and processing is terminated.

A.7.4 Program Description (See Figure A.56)

A.7.4.1 Main Program

The processing in the TRSRT program begins with the initialization of the data set reference numbers and the aircraft counters. Aircraft type and description data from the TAPE2 file is then read and stored in the IACTYP and IACDES arrays. Data are read until an end of file is detected or 30 aircraft are read. The total number of aircraft read is save in IAC. At 9, the day of the week number (1-Monday, 2-Tuesday, etc.) and the title of the run are read from TAPE1. If an end of file is detected during this operation, the program execution is terminated. The day of the week and title data are then repeated on the output file TAPE3. Next, the arrival-departure record is read into the IAD array from TAPE1. If an end of file is detected, an error comment is printed at 98 and the program is terminated. Then, two tests are made on the first four characters in the IAD array. If these characters are ARRI, then control goes to 10 where the switch ISW is set to 0 and the program jumps to 12. If these characters are DEPA, then the program jumps to 11 and ISW is set to 1.

At 12 a DO loop is entered with the index, I, running from 1 to 400. The first step in the DO loop is to read the first city card in the TAPE1 file.

copy,tape3

ARRIVAL-DEPARTURE DATA SORT FOR DAY OF THE WEEK,5   INDIANAPOLIS

1140	AKRON/CANTON,OH	CAK	AL	151	D9S
1604	AKRON/CANTON,OH	CAK	AL	185	D9S
2014	AKRON/CANTON,OH	CAK	AL	447	B11
47	ATLANTA,GA	ATL	EA	462	DC9
50	ATLANTA,GA	ATL	DL	690	DC9
944	ATLANTA,GA	ATL	EA	688	727
1024	ATLANTA,GA	ATL	DL	460	72S
1215	ATLANTA,GA	ATL	EA	296	DC9
1533	ATLANTA,GA	ATL	EA	264	D9S
1828	ATLANTA,GA	ATL	DL	766	D9S
1924	ATLANTA,GA	ATL	EA	266	D9S
2042	ATLANTA,GA	ATL	DL	438	72S
913	BALTIMORE,MD	BAL	AL	225	D9S
1554	BALTIMORE,MD	BAL	AL	277	D9S
620	BLOOMINGTON,IND	BMG	AL	642	BE9
745	BLOOMINGTON,IND	BMG	AL	644	BE9
1105	BLOOMINGTON,IND	BMG	AL	646	BE9
1425	BLOOMINGTON,IND	BMG	AL	648	BE9
1550	BLOOMINGTON,IND	BMG	AL	650	BE9
1745	BLOOMINGTON,IND	BMG	AL	652	BE9
948	BUFFALO,NY	BUF	AL	165	D9S
1606	BUFFALO,NY	BUF	AL	437	B11
727	CHICAGO,ILL	CHI	AA	354	72S
853	CHICAGO,ILL	CHI	AL	498	B11
923	CHICAGO,ILL	CHI	DL	869	D9S
1047	CHICAGO,ILL	CHI	AL	138	D9S
1129	CHICAGO,ILL	CHI	AA	238	707
1355	CHICAGO,ILL	CHI	DL	359	72S
1502	CHICAGO,ILL	CHI	AL	194	D9S
1514	CHICAGO,ILL	CHI	AA	166	707
1632	CHICAGO,ILL	CHI	AL	222	D9S
1746	CHICAGO,ILL	CHI	AA	182	D10
2057	CHICAGO,ILL	CHI	AL	192	D9S
1017	CINCINNATI,OH	CVG	AA	429	72S
1642	CINCINNATI,OH	CVG	TW	139	707
1702	CINCINNATI,OH	CVG	AA	471	72S
2059	CINCINNATI,OH	CVG	AL	479	B11
2127	CINCINNATI,OH	CVG	AA	453	72S
1759	COLUMBUS,OH	CMH	TW	531	72S
842	DALLAS/FT.WORTH,TX	DFW	AA	84	707
1500	DALLAS/FT.WORTH,TX	DFW	AA	618	72S
2047	DALLAS/FT.WORTH,TX	DFW	AA	622	707
1909	DAYTON,OH	DAY	TW	129	DC9
1127	DAYTON,OH	DAY	AL	135	D9S
1603	DAYTON,OH	DAY	TW	189	L10
1606	DAYTON,OH	DAY	AL	241	D9S
2153	DAYTON,OH	DAY	AL	425	B11
2302	DAYTON,OH	DAY	TW	279	72S

time (hours, minutes)

city of origin

airport code

airline

flight number

type of aircraft

Figure A.55 Traffic Output Data from TRSRT (Page 1 of 2)

TRAFFIC FOR TIMES BETWEEN 900 AND 1000

TIME	ORIGIN	CODE	FLIGHT	AIRCRAFT
913	BALTIMORE,MD	BAL	AL 225	D9S
923	CHICAGO,ILL	CHI	DL 869	D9S
944	ATLANTA,GA	ATL	EA 688	727
948	BUFFALO,NY	BUF	AL 165	D9S

D9S	B11	DC9	727	72S	BE9	707	D10	L10	737	73S
3	0	0	1	0	0	0	0	0	0	0

747	UNC
0	0

TRAFFIC FOR TIMES BETWEEN 1000 AND 1100

TIME	ORIGIN	CODE	FLIGHT	AIRCRAFT
1009	DAYTON,OH	DAY	TW 129	DC9
1017	CINCINNATI,OH	CVG	AA 429	72S
1024	ATLANTA,GA	ATL	DL 460	72S
1047	CHICAGO,ILL	CHI	AL 138	D9S

D9S	B11	DC9	727	72S	BE9	707	D10	L10	737	73S
1	0	1	0	2	0	0	0	0	0	0

747	UNC
0	0

TRAFFIC FOR TIMES BETWEEN 1100 AND 1200

TIME	ORIGIN	CODE	FLIGHT	AIRCRAFT
1105	BLOOMINGTON,IND	BMG	AL 646	BE9
1127	DAYTON,OH	DAY	AL 135	D9S
1129	CHICAGO,ILL	CHI	AA 238	707
1140	AKRON/CANTON,OH	CAK	AL 151	D9S

D9S	B11	DC9	727	72S	BE9	707	D10	L10	737	73S
2	0	0	0	0	1	1	0	0	0	0

747	UNC
0	0

TRAFFIC FOR TIMES BETWEEN 1200 AND 1300

TIME	ORIGIN	CODE	FLIGHT	AIRCRAFT
1215	ATLANTA,GA	ATL	EA 296	DC9

D9S	B11	DC9	727	72S	BE9	707	D10	L10	737	73S
0	0	1	0	0	0	0	0	0	0	0

747	UNC
0	0

Figure A.55 Traffic Output Data from TRSRT (Page 2 of 2)

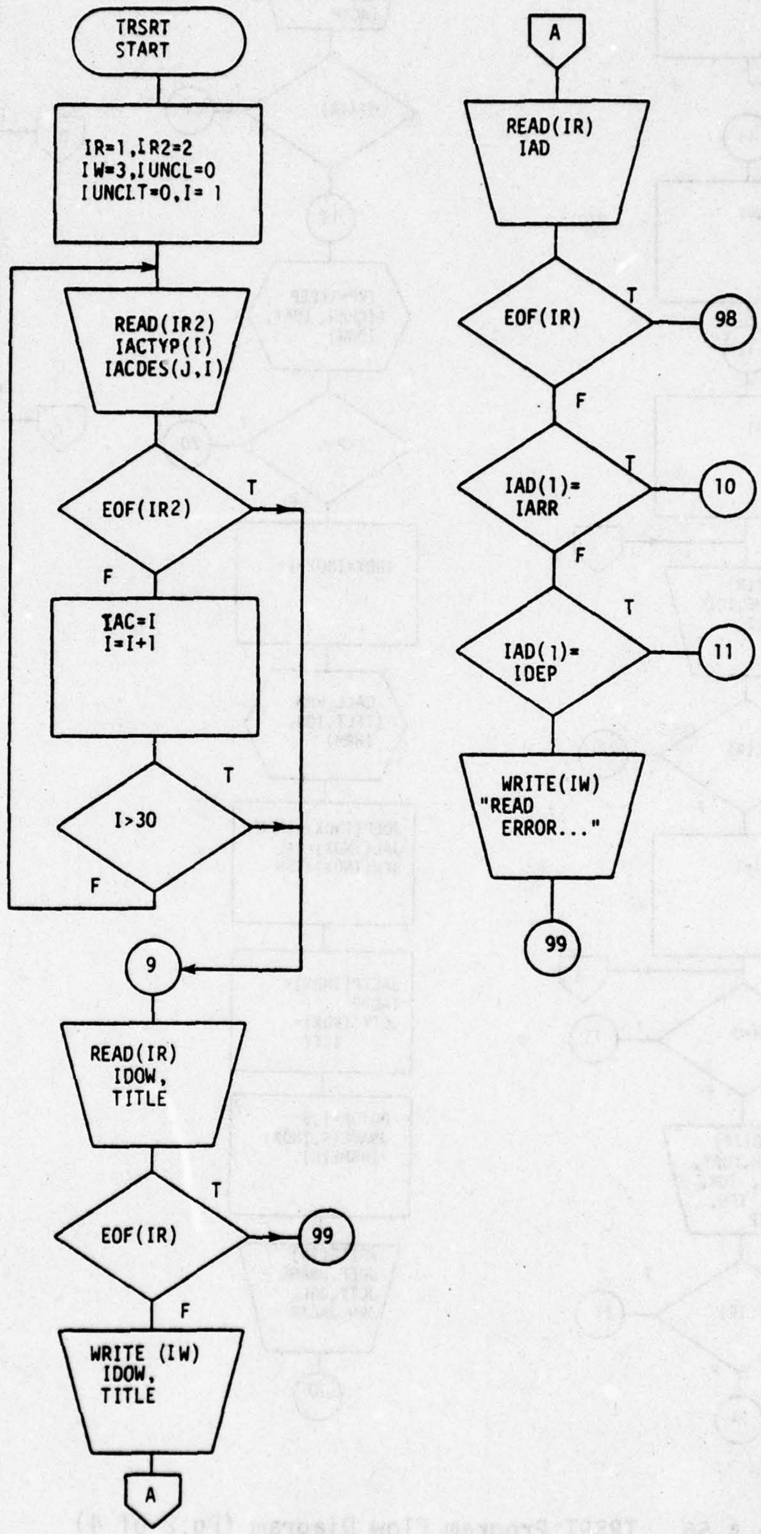


Figure A.56 TRSRT Program Flow Diagram (Pg. 1 of 4)

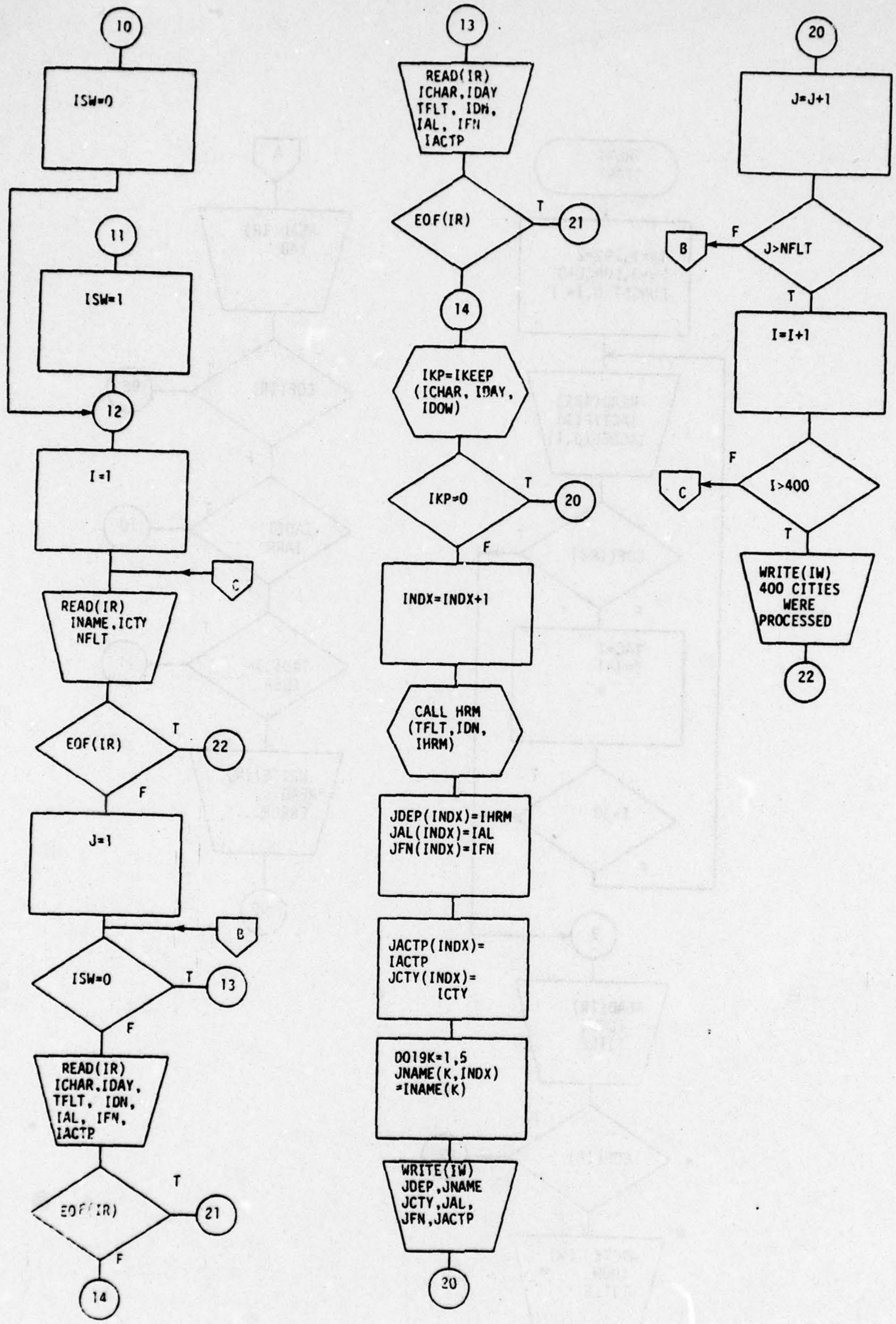


Figure A.56 TRSRT Program Flow Diagram (Pg.2 of 4)

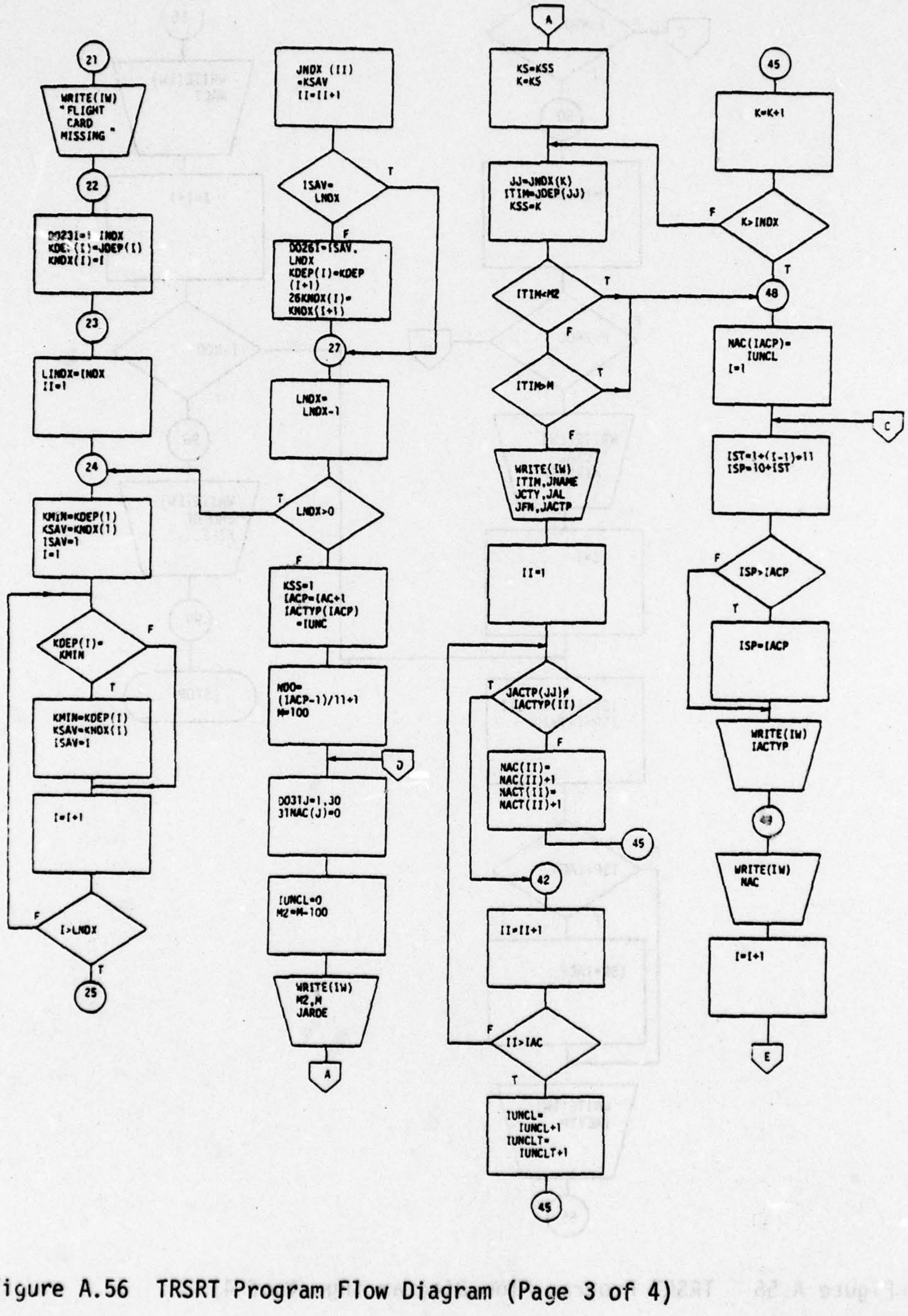


Figure A.56 TRSRT Program Flow Diagram (Page 3 of 4)

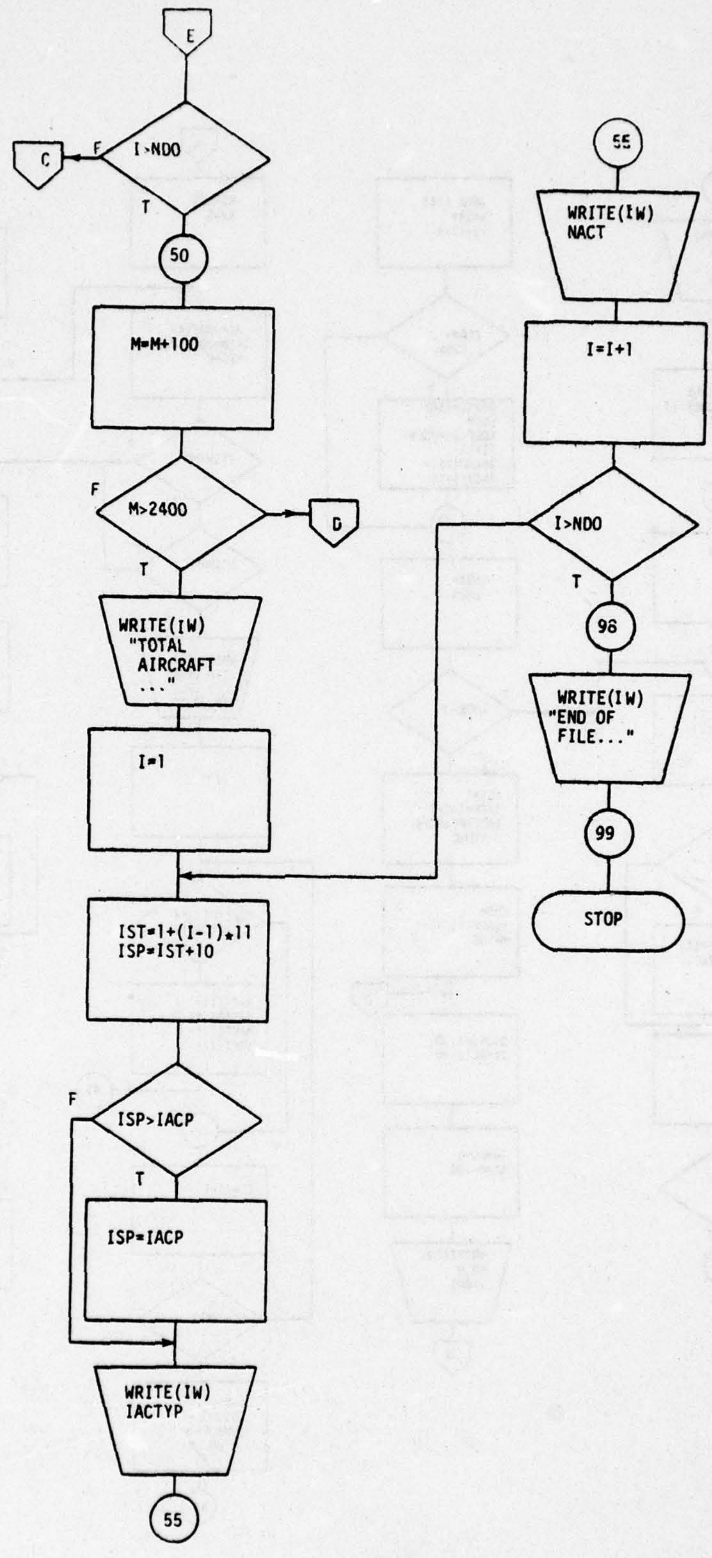


Figure A.56 TRSRT Program Flow Diagram (Pg. 4 of 4)

This card image contains the city's name, INAME, the city's three letter code, ICTY, and the number of flight records NFLT, for that city. An end of record in the TAPE1 file causes a jump to 22 which is a normal termination of the DO loop. Next an inner DO loop is entered with the index J running from 1 to NFLT, the number of flight records for the city. A test on ISW is made to determine whether arrivals or departures are being processed as the read format for the flight card is different for arrivals and departures. The flight parameters ICHAR, IDAY, TFLT, IDN, IAL, IFN and IACTP are read from each flight record. The format and data content of these parameters are described in Section A.7.2. If an end of file is detected in either the arrival or the departure read statement, the program jumps to 21 whereupon an error comment is printed and processing continues at 22 which is outside the range of both DO loops. Normally, the processing goes to 14 after the READ instruction. At 14, IKP is computed from the IKEEP function. IKEEP processes the day-of-the-week data from the flight record (ICHAR and IDAY) and compares this data with the specified day-of-the-week, IDOW. If the flight operates on the specified day, IKEEP returns a value of 1 while a value of 0 means the flight does not operate on the selected day. The value of IKP is then tested. A value of 0 sends the program to 20 where the inner DO index J is incremented by 1 and the program returns to read the next flight record. If IKP is not equal to zero, the flight counter INDEX is incremented by 1 and interpretation of the flight data is begun.

The flight arrival or departure time is converted to a 24 hour clock by the HRM subroutine. The 24 hour value is returned from HRM as the value of IHRM. This value is stored in the JDEP array. Similarily, the values of the other flight data are stored in the following arrays.

Array	Flight Data
JAL	IAL
JFN	IFN
JACTP	IACTP
JCTY	ICTY
JNAME(K)	INAME(K)

These array values are all stored at the location in the array given by the flight counter value, INDX. The array values are then written on TAPE3 for the purpose of cross checking with the input data from TAPE1. Next, the inner DO index is incremented by 1 and the next flight record is read. When the inner DO loop has been completed, the outer DO loop is incremented by one and the next city record is read. If no more city cards are available, processing jumps to 22. If the outer DO index exceeds 400 then a comment is printed on TAPE3 to the effect that 400 city records were read. Additional city data is then ignored so that the capacity of the program will not be exceeded. Processing then goes to 22.

At 22 the sort on the aircraft arrival or departure time begins. First a copy of the JDEP array of aircraft times is written in KDEP and the index values of the JDEP array are written in the KNDX array. Next, the index counter LINDX is set to the number of flight records to be sorted which is stored in INDEX, and the counter II is set to 1. At 24 the values of KMIN and KSAV are

initialized to the first time record (KDEP(1) and the index number (in the JDEP array) associated with that value of KDEP(1). The index value of this time in the KDEP array, which is 1, is also saved in ISAV. Then a DO loop is entered which looks for the minimum time value in the KDEP array. At the end of the DO loop the time value in KMIN is the minimum of the first through LNDX records in KDEP. KSAV contains the index number of that value in the JDEP array and ISAV contains the index number of that value in the KDEP array. At 25 the index value in KSAV is stored at the appropriate location, II, in the JNDX array and II is incremented by 1 to prepare for the next index value. At 26 a DO loop is entered which essentially throws out the minimum value of time in KDEP(ISAVE) and moves the remaining records up to close the gap. LNDX is then decremented by 1 and tested to see if there are unsorted records remaining in the KDEP array. If so processing returns to 24 to look for the next minimum time in KDEP. When all the KDEP records have been sorted JDEP still contains all of the time values and JNDX contains the addresses of the sorted time values; that is for example, if the minimum time is in JDEP(28) and the next least time is in JDEP(10), then JNDX(1)=28, JNDX(2)=10, etc.

When all of the records in KDEP have been sorted, the procedure for listing the data in hourly segments is begun. The index value of JNDX associated with the first unprinted record of time in the JDEP array is stored in KSS. KSS is thus initialized to the value 1. The value of 1 plus the number of aircraft types read from input is stored in IACP. This permits the assignment of the unclassified aircraft to the last aircraft type category (IACTYP(IACP)=IUNC). The number of output lines of aircraft type data is stored in NDO. The aircraft types are printed 11 on each line. Then a DO loop on the arrival-departure time is entered. M is the DO index and M represents time in hours and minutes; that is for example M=736 means 36 minutes past 7:00am, while 1545 means 45 minutes past 3:00 pm. M is incremented in 1 hour (100) increments and the DO loop stops when M exceeds 24 hours (2400). The aircraft type counters NAC are set to zero at 31. The unclassified aircraft counter IUNCL is also set to zero. The time interval in question starts at M2=M-100 and ends at M. These values are written on TAPE3. The index counter for the sorted and printed time records is set at the start point by the instruction KS=KSS and an inner DO loop is begun which tests the aircraft times ITIM to see if it is in the appropriate range of M2 and M to be printed. If not, the DO loop is exited by jumping to 48. If the time ITIM is in the range, its value along with the city name, code, airline and flight number, and the aircraft type is written on TAPE3. Next, another DO is entered with II as the DO index. This loop searches through the aircraft identifiers IACTYP(II) and compares these types with the identifier of the aircraft in the flight record under consideration, JACTP(JJ). If the identifiers match the counter NAC(II) and NACT(II) are increased by 1. If no match is found for all stored identifiers 1-IAC, then the unclassified aircraft counters IUNCL and IUNCLT are incremented by 1. The flight record counter K is then incremented by 1 and the next flight record is processed beginning at the top of the inner DO loop. If the next value of aircraft time ITIM is out of range of M2 and M or if all records have been processed (K>INDX), then processing jumps to 48. At 48 the last aircraft counter value is assigned to the unclassified aircraft. Another inner DO loop is entered to print the lines of aircraft counter data for the range of time between M2 an M. The IST and ISP values are start-stop values of the array

indices on IACTYP and NAC. When all lines have been printed (I>NDO) then the next hourly traffic data is written on TAPE3 by incrementing M by 100 (1 hour) and returning to the top of the outer DO loop.

When all 24 hours have been processed, the total aircraft type data for all 24 hours is written on TAPE3. This procedure is virtually identical to the hourly aircraft data output section (DO 49 I=1,NDO) except that the total aircraft data array NACT is used instead of the NAC array. When all lines of data have been written the program jumps to 99 where processing is terminated.

A.7.4.2 TRSRT Subprograms (See Figures A.57 and A.58)

The TRSRT program uses two external subprograms, the IKEEP function and the HRM subroutine. The IKEEP function determines whether the flight operates on the specified day-of-the-week stored in the argument list parameter IDOW. IKEEP=1 means the flight does operate, IKEEP=0 means no flight operations. IDOW is an integer ranging from 1 to 7 with 1 meaning Monday, 2-Tuesday, etc. The other argument list data is ICHAR and IDAY. If ICHAR is an X it means the flight operates every day except those stored in IDAY. If ICHAR is any other character then the flight operates on the days specified in IDAY. If the IDAY array is entirely blank, then the flight operates every day. The first part of the subprogram checks for blank or zero values for IDAY. If IDAY is all blank, ISUM is zero and the program jumps to 30 where IKEEP is set to 1 and control is returned to the main program. During the DO loop that computes ISUM, IDAY(I) and IDOW are compared. If they are equal, processing jumps to 20. At 20 a test is made on ICHAR to see if it contains the character X. If not, processing jumps to 30 where IKEEP is set to 1 and the return is made. If an X is found, processing jumps to 15 where IKEEP is set to 0 and the RETURN is made. If ISUM is non-zero and ICHAR does not contain an X then IKEEP is set to zero and control returns to the calling program.

The HRM subroutine is used to convert time to the 24 hour format. The argument list contains the flight time T where hours are represented by whole numbers and minutes by the fraction. The argument J contains one of 4 characters A-am, P-pm, N-noon, M-midnight. The argument IHRM is an integer ranging from 0 to 2359. Zero represents midnight and 2359 means 11:59 pm. The conversion from floating point time T to integer time IHRM is done by adding a small correction value of .005 minutes to T to prevent round off and truncation error.

A.7.5 <u>Program Listing</u>

Listings of the TRSRT program and the IKEEP and HRM subprograms are shown in Figures A.59-A.61.

A.8 PROGRAM TRPUN

A.8.1 <u>Purpose of Program</u>

The TRPUN program is used to prepare traffic demand data for use by the TROPT and TEVALP programs. The traffic data can come from the "Official Airline Guide" data that is described in the TRSRT program section. The resulting demand data consists of the city code, the number of arrival flights from that city and the number of departure flights to the same city. These data thus provide

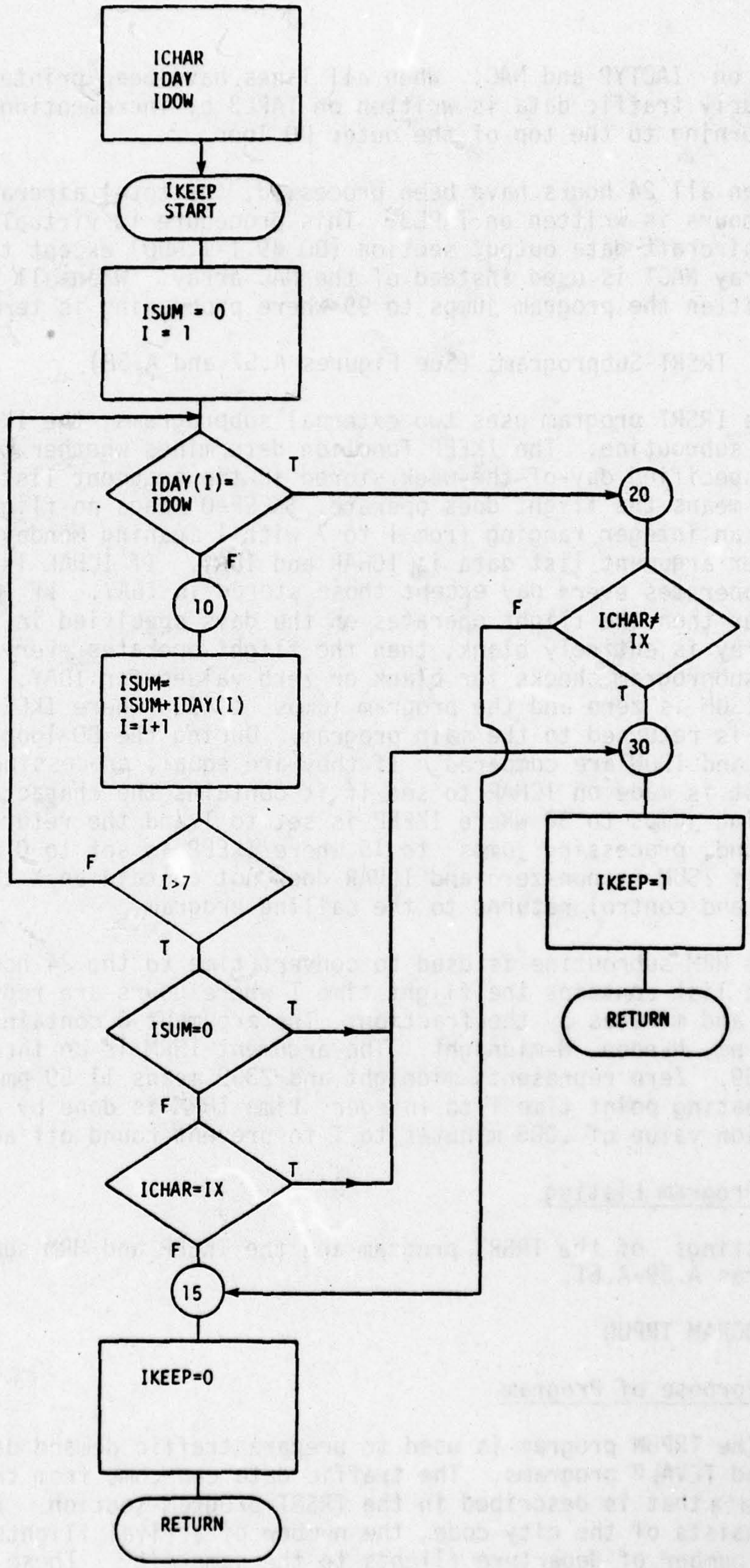


Figure A.57 IKEEP Function Flow Diagram

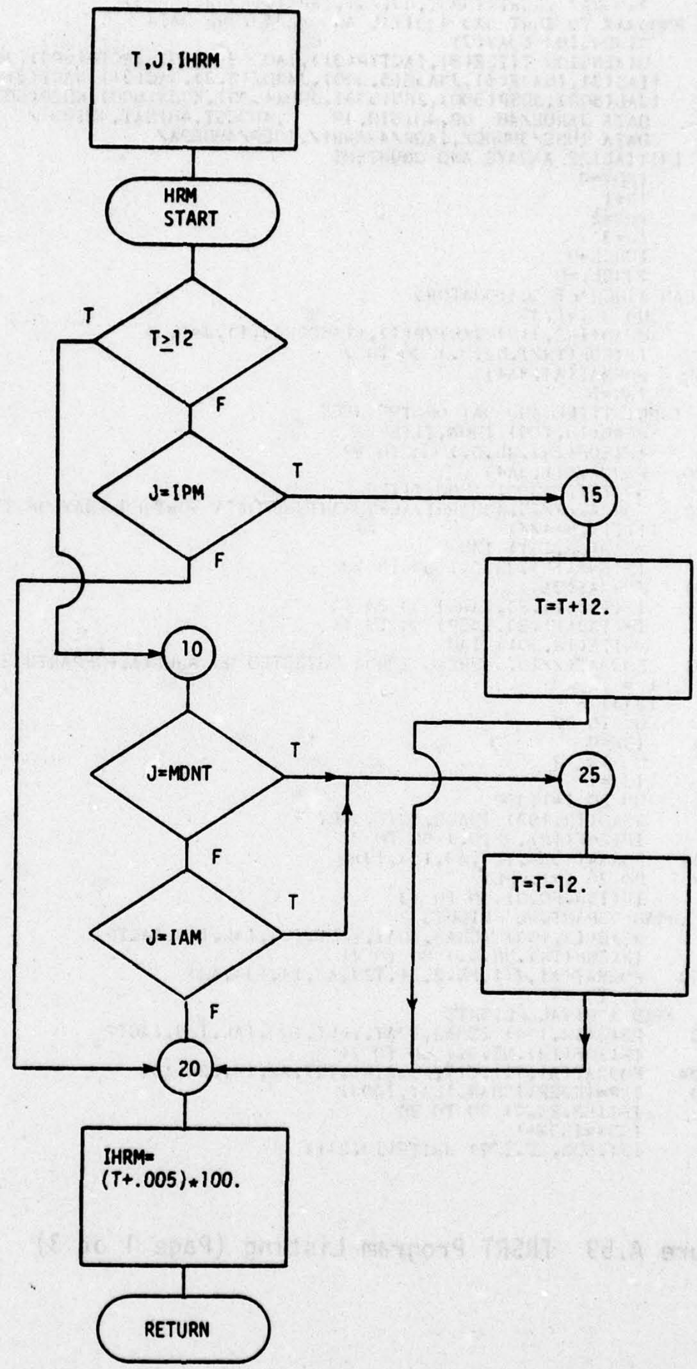


Figure A.58 HRM Subroutine Flow Diagram

```
      PROGRAM TRSRT(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3)
*  PROGRAM TO SORT OAG ARRIVAL AND DEPARTURE DATA
      DIMENSION IDAY(7)
      DIMENSION TITLE(8),IACTYP(31),IACDES(3,30),JACTP(500),JCTY(500),
     1IAD(3),INAME(5),JNAME(5,500),JARDE(3,2),NAC(31),NACT(31),
     1JAL(500),JDEP(500),JFN(500),JNDX(500),KNDX(500),KDEP(500)
      DATA JARDE/4H  OR,4HIGIN,4H    ,4HDEST,4HINAT,4HION /
      DATA IUNC/3HUNC/,IARR/4HARRI/,IDEP/4HDEPA/
*  INITIALIZE ARRAYS AND COUNTERS
      INDX=0
      IR=1
      IR2=2
      IW=3
      IUNCL=0
      IUNCLT=0
*READ AIRCRAFT DESIGNATORS
      DO 3 I=1,30
      READ(IR2,110) IACTYP(I),(IACDES(J,I),J=1,3)
      IF(EOF(IR2).NE.0.) GO TO 2
110   FORMAT(A4,3A4)
3     IAC=I
*  INPUT TITLE AND DAY OF THE WEEK
2     READ(IR,100) IDOW,TITLE
      IF(EOF(IR).NE.0.) GO TO 99
100   FORMAT(I1,8A4)
      WRITE(IW,200) IDOW,TITLE
200   FORMAT(//T5,43HARRIVAL-DEPARTURE DATA SORT FOR DAY OF THE WEEK,
     1I1,1X,8A4//)
      READ(IR,101) IAD
      IF(EOF(IR).NE.0.) GO TO 23
101   FORMAT(3A4)
      IF(IAD(1).EQ.IARR) GO TO 10
      IF(IAD(1).EQ.IDEP) GO TO 11
      WRITE(IW,201) IAD
201   FORMAT(//T5,54HREAD ERROR DETECTED ON ARRIVAL-DEPARTURE CARD IMAGE
     1 = ,
     13A4)
      GO TO 99
10    ISW=0
      GO TO 12
11    ISW=1
12    DO 20 I=1,400
      READ(IR,102) INAME,ICTY,NFLT
      IF(EOF(IR).NE.0.) GO TO 22
102   FORMAT(5A4,T23,A3,T34,I3)
      DO 20 J=1,NFLT
      IF(ISW.EQ.0) GO TO 13
*  READ DEPARTURE FLIGHTS
      READ(IR,103) ICHAR,IDAY,TFLT,IOR,IAL,IFN,IACTP
      IF(EOF(IR).NE.0.) GO TO 21
103   FORMAT(A1,7I1,F5.2,A1,T27,A2,I4,T34,A3)
      GO TO 14
*  READ ARRIVAL FLIGHTS
13    READ(IR,104) ICHAR,IDAY,TFLT,IOR,IAL,IFN,IACTP
      IF(EOF(IR).NE.0.) GO TO 21
104   FORMAT(A1,7I1,T17,F5.2,A1,T27,A2,I4,T34,A3)
14    IKP=IKEEP(ICHAR,IDAY,IDOW)
      IF(IKP.EQ.0) GO TO 20
      INDX=INDX+1
      IF(INDX.GT.500) WRITE(IW,211)
```

Figure A.59 TRSRT Program Listing (Page 1 of 3)

```
211   FORMAT(//26H500 FLIGHTS WERE PROCESSED)
      IF(INDX.GT.500) GO TO 20
      CALL HRM(TFLT,IDN,IHRM)
      JDEP(INDX)=IHRM
      JAL(INDX)=IAL
      JFN(INDX)=IFN
      JACTP(INDX)=IACTP
      JCTY(INDX)=ICTY
      DO 19 K=1,5
19    JNAME(K,INDX)=INAME(K)
      WRITE(IW,205) JDEP(INDX),(JNAME(L,INDX),L=1,5),JCTY(INDX),JAL(INDX
     1),
     1JFN(INDX),JACTP(INDX)
20    CONTINUE
      WRITE(IW,202)
202   FORMAT(//25H400 CITIES WERE PROCESSED)
*  SORT FLIGHTS BY TIME
      GO TO 22
21    WRITE(IW,203)
203   FORMAT(//T5,19HFLIGHT CARD MISSING)
22    DO 23 I=1,INDX
      KDEP(I)=JDEP(I)
23    KNDX(I)=I
      LNDX=INDX
      II=1
24    KMIN=KDEP(1)
      KSAV=KNDX(1)
      ISAV=1
      DO 25 I=1,LNDX
      IF(KDEP(I).GE.KMIN) GO TO 25
      KMIN=KDEP(I)
      KSAV=KNDX(I)
      ISAV=I
25    CONTINUE
      JNDX(II)=KSAV
      II=II+1
      IF(ISAV.EQ.LNDX) GO TO 27
      DO 26 I=ISAV,LNDX
      KDEP(I)=KDEP(I+1)
26    KNDX(I)=KNDX(I+1)
27    LNDX=LNDX-1
      IF(LNDX.GT.0) GO TO 24
*  PRINT DEPARTURES BY CHRONOLOGICAL ORDER AND ACCUMULATE AIRCRAFT BY
*  TYPE
      KSS=1
      IACP=IAC+1
      IACTYP(IACP)=IUNC
      NDD=(IACP-1)/11+1
      DO 50 M=100,2400,100
      DO 31 J=1,30
31    NAC(J)=0
      IUNCL=0
      M2=M-100
      WRITE(IW,204) M2,M,(JARDE(KL,ISM+1),KL=1,3)
204   FORMAT(//T5,25HTRAFFIC FOR TIMES BETWEEN,I5,4H AND,I5//T7,4HTIME,
     1T17,3A4,T35,4HCODE,T41,6HFLIGHT,T49,8HAIRCRAFT/)
      KS=KSS
      DO 45 K=KS,INDX
      JJ=JNDX(K)
      ITIM=JDEP(JJ)
```

Figure A.59 TRSRT Program Listing (Page 2 of 3)

```
      KSS=K
      IF(ITIM.LT.M2) GO TO 48
      IF(ITIM.GE.M) GO TO 48
      WRITE(IW,205) ITIM,(JNAME(KK,JJ),KK=1,5),JCTY(JJ),JAL(JJ),JFN(JJ),
     1JACTP(JJ)
205   FORMAT(T7,I4,T13,5A4,T36,A3,T41,A2,I4,T52,A3)
      DO 42 II=1,IAC
      IF(JACTP(JJ).NE.IACTYP(II)) GO TO 42
      NAC(II)=NAC(II)+1
      NACT(II)=NACT(II)+1
      GO TO 45
42    CONTINUE
      IUNCL=IUNCL+1
      IUNCLT=IUNCLT+1
45    CONTINUE
48    NAC(IACP)=IUNCL
      DO 49 I=1,NDO
      IST=1+(I-1)*11
      ISP=11+(I-1)*11
      IF(ISP.GT.IACP) ISP=IACP
      WRITE(IW,232)
      WRITE(IW,220) (IACTYP(J),J=IST,ISP)
220   FORMAT(T5,11(A3,3X))
232   FORMAT(/)
49    WRITE(IW,221) (NAC(J),J=IST,ISP)
221   FORMAT(T5,11(I3,3X))
50    CONTINUE
      WRITE(IW,222)
222   FORMAT(///,T5,22HTOTAL AIRCRAFT BY TYPE,/)
      DO 55 I=1,NDO
      IST=1+(I-1)*11
      ISP=11+(I-1)*11
      IF(ISP.GT.IACP) ISP=IACP
      WRITE(IW,232)
      WRITE(IW,220) (IACTYP(J),J=IST,ISP)
55    WRITE(IW,221) (NACT(J),J=IST,ISP)
      GO TO 99
98    WRITE(IW,230)
230   FORMAT(/T5,33HEND OF FILE DETECTED FOR IAD CARD,/)
99    STOP
      END
```

Figure A.59 TRSRT Program Listing (Page 3 of 3)

```
      FUNCTION IKEEP(ICHAR,IDAY,IDOW)
      DIMENSION IDAY(7)
      DATA IX/1HX/,IBL/1H /
      ISUM=0
      DO 10 I=1,7
      IF(IDAY(I).EQ.IDOW) GO TO 20
10    ISUM=ISUM+IDAY(I)
      IF(ISUM.EQ.0) GO TO 30
      IF(ICHAR.EQ.IX) GO TO 30
15    IKEEP=0
      RETURN
20    IF(ICHAR.NE.IX) GO TO 30
      GO TO 15
30    IKEEP=1
      RETURN
      END
```

Figure A.60 IKEEP Function Listing

```
      SUBROUTINE HRM(T,J,IHRM)
      DATA NOON/1HN/,MDNT/1HM/,IAM/1HA/,IPM/1HP/
      IF(T.GE.12.0) GO TO 10
      IF(J.EQ.IPM) GO TO 15
      GO TO 20
10    IF(J.EQ.MDNT) GO TO 25
      IF(J.EQ.IAM) GO TO 25
20    IHRM=(T+.005)*100.
      RETURN
25    T=T-12.
      GO TO 20
15    T=T+12.
      GO TO 20
      END
```

Figure A.61 HRM Subroutine Listing

the traffic demand part of the information needed by TROPT AND TEVALP. These two programs make use of the average demand ((arrivals + departures)/2) and the great circle bearing angle to the specified city. Thus the bearing information must come from another data source and the traffic data from TRPUN needs to be averaged before it can be used by TROPT and TEVALP.

A functional diagram of the TRPUN program is shown in Figure A.62. It can be seen that the input data closely corresponds to the input data used by TRSRT. The major difference concerns the fact that both arrival and departure data is used by TRPUN while TRSRT processes either arrival or departure data but not both during the same run. The processing for TRPUN is generally straightforward. The program control data are read first, followed by departure data which in turn are followed by arrival data. Errors in input data will be flagged if they do not cause the program execution to abort. The output is intended for line printer processing as the data must be augmented with the great circle bearing angle in order to be used by the TROPT and TEVALP programs.

A.8.2 Input Data

The input data used by TRPUN comes from two input files TAPE1 and TAPE2. TAPE1 contains the departure data and TAPE2 the arrival data. The format and data content of these files is identical to that contained in the TAPE1 file for the TRSRT program described in Section A.7.2.

A.8.3 Output Data

Output data are written on the TAPE3 and TAPE4 output files. The data written on the TAPE3 file contains the program control data contained on the input data records, the city codes, departure traffic counts and arrival traffic counts, and error messages if errors have been detected in the input records. The TAPE4 data consist of only the city code, departure traffic count and arrival counts. The format of the output data is as follows:

CHARACTERS	NAME	FORMAT	DESCRIPTION
1-3	JCTY	A3	three letter city code
4-5	—	—	blank
6-10	ND	I5	departure traffic count (aircraft/day)
11-15	NA	I5	arrival traffic count (aircraft/day)

An example of the output written by TRPUN on the TAPE3 file is shown in Figure A.63.

A.8.4 Program Description

A detailed flow diagram of the TRPUN program is shown in Figure A.64. The program begins by initializing the JCTY array to blank characters and the NA and ND arrays to zero. The data set reference numbers are initialized next. Then, the program control data is read from the TAPE1 file. The day of the week selected for the traffic demand data is read and stored in IDOW. The title of the data run is also read from the same record and stored in TITLE. If an end of file is detected during the READ instruction, the program execution is

PROGRAM TRPUN

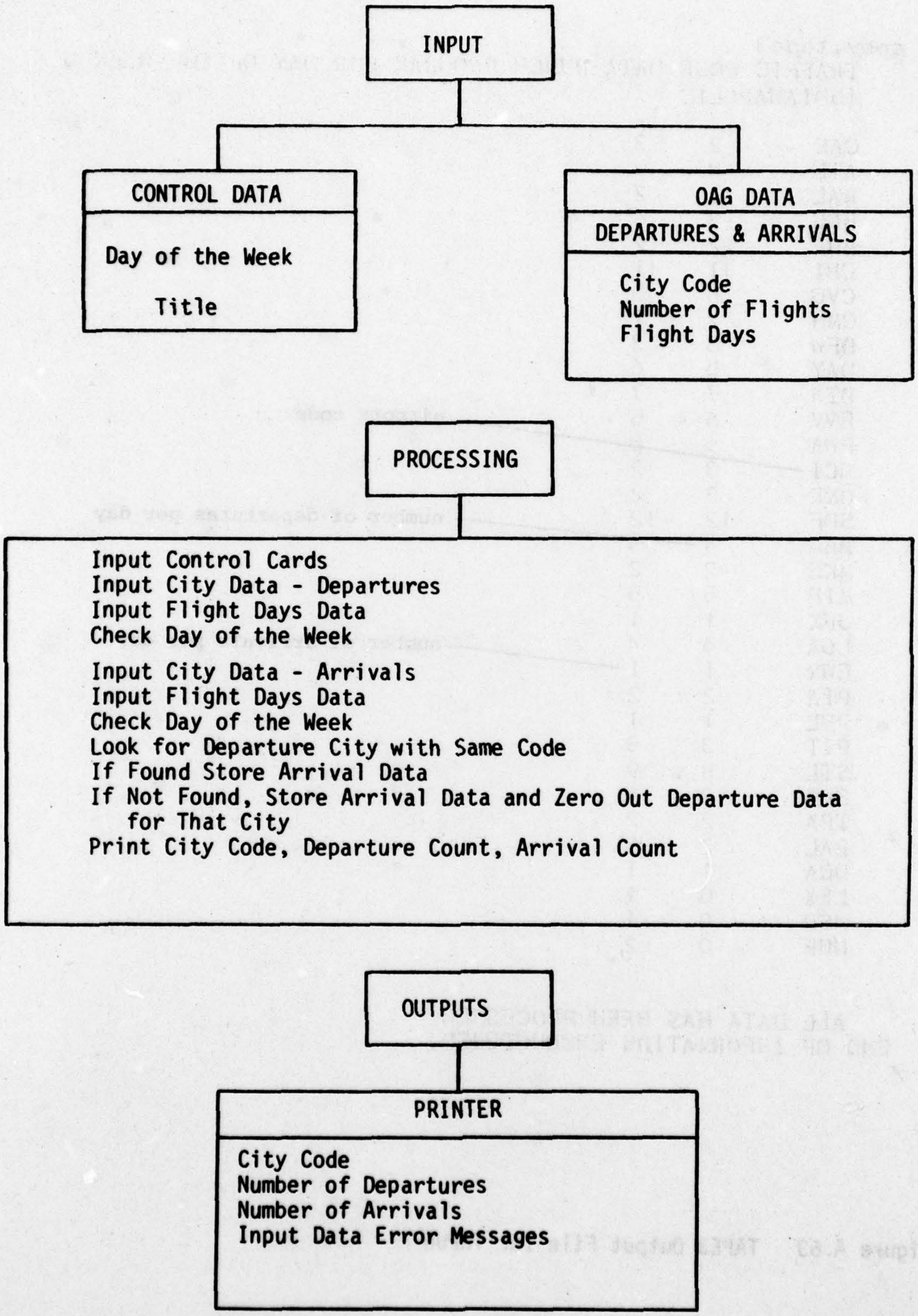


Figure A.62 TRPUN Program Functional Diagram

```
copy,tape3
   TRAFFIC ROSE DATA PUNCH PROGRAM FOR DAY OF THE WEEK 5
   INDIANAPOLIS

   CAK        2     3
   ATL        8     9
   BAL        2     2
   BMG        3     6
   BUF        2     2
   CHI       11    11
   CVG        5     5
   CMH        2     1
   DFW        3     3
   DAY        5     6
   DTW        7     7
   EVV        6     5             airport code
   FWA        5     5
   MCI        3     2
   OKK        2     2
   SDF       12    12             number of departures per day
   MEM        4     4
   MKE        2     2
   MIE        5     5
   JFK        1     1
   LGA        4     4             number of arrivals per day
   EWR        1     1
   PIA        2     2
   PHL        1     1
   PIT        3     3
   STL        8     9
   SBN        2     1
   T[illegible]A        2     2
   [illegible]        2     0
   [illegible]        1     1
   LEX        0     1
   MSP        0     1
   HUF        0     2

    ALL DATA HAS BEEN PROCESSED
  END OF INFORMATION ENCOUNTERED.
/
```

Figure A.63 TAPE3 Output File for TRPUN

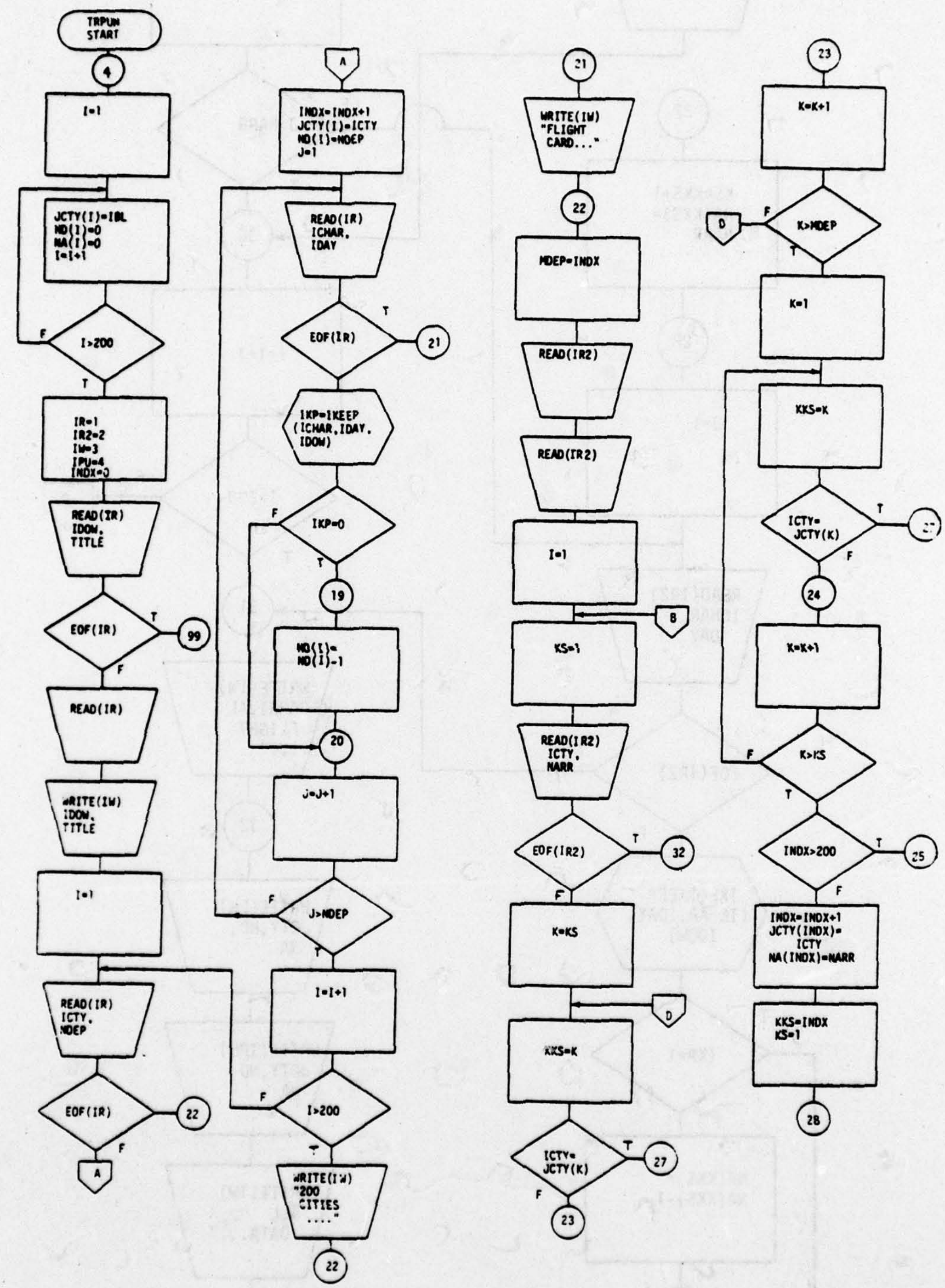


Figure A.64 TRPUN Program Flow Diagram (Pg. 1 of 2)

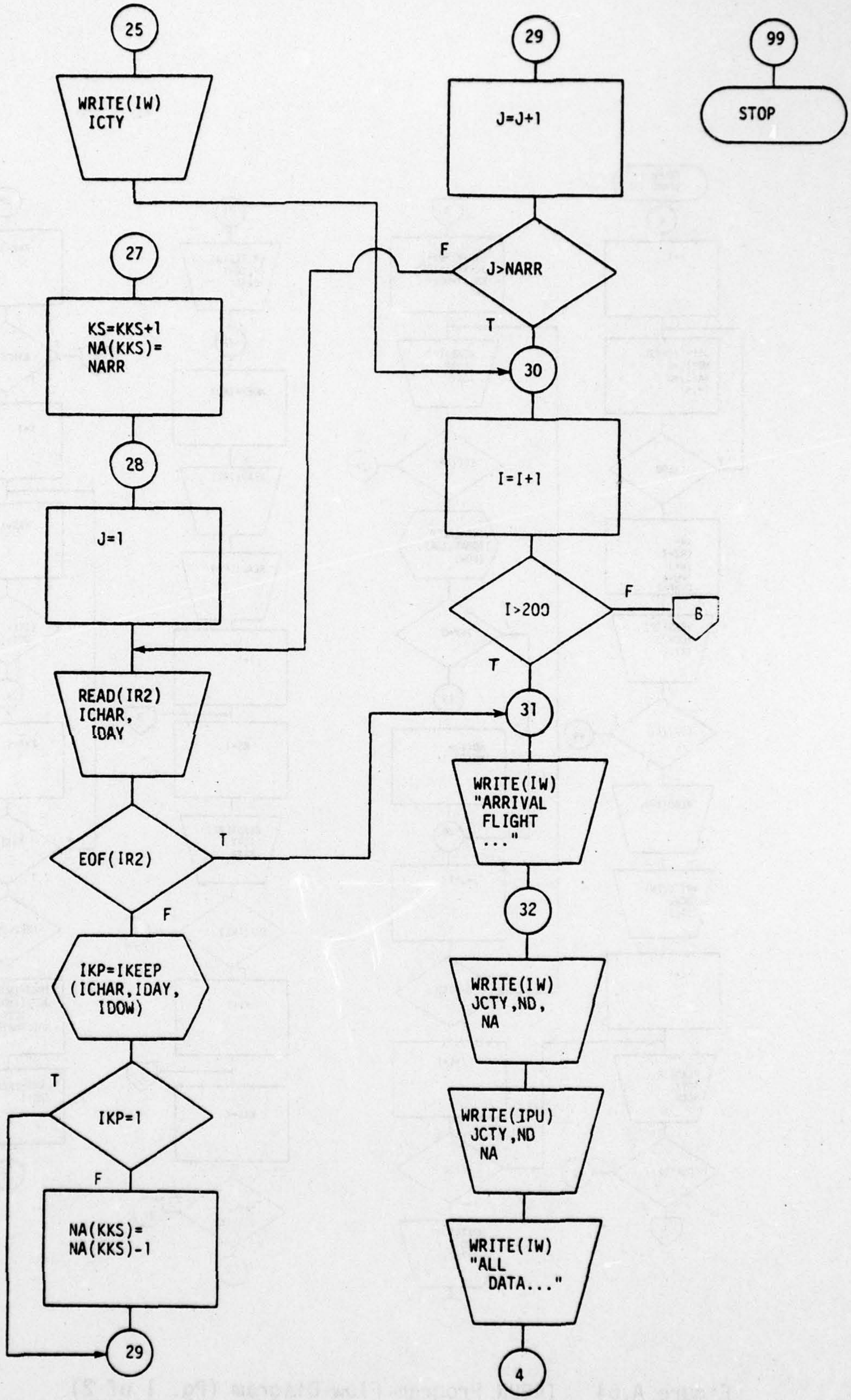


Figure A.64 TRPUN Program Flow Diagram (Pg.2 of 2)

terminated. Next, one more READ statement is executed to skip the second record in the TAPE1 file. This contains the characters DEPARTURE which is used in the TRSRT prgram but is unused in the TRPUN program. The day of the week value and the title of the run are then written on the TAPE3 file.

The input of the departure data is performed in a DO loop with the DO parameter running from 1 to 200. The arrays storing arrival, departure and city name data contain 200 elements. The first record that is read contains the city code and the number of flight records following the city card. These data are stored in ICTY and NDEP. If an end of file is detected during the reading of a city card, the program jumps to 22. This is the normal exit from the DO loop with the index I. The counter INDX is advanced by 1 and the values of ICTY and NDEP are stored in the JCTY and ND arrays. Next, an inner DO is entered with the index J running from 1 to NDEP, the number of flight records for the city. The values of ICHAR and IDAY are then read from TAPE1 and tested for an end of file condition. If the test indicates the end of file on TAPE1, then flight records are missing and the program control jumps to 21 where this comment is written on TAPE3. Otherwise, the values of ICHAR and IDAY are used by the IKEEP subprogram to determine if the specified flight operates on the day of the week stored in IDOW. If the flight does not operate, IKP equals 0 and the program goes to 19 and reduces the number of departures in ND(I) by 1. Otherwise, the program jumps to 20 which is the termination of both the inner and outer DO loops. If more than 200 cities are contained in the input stream, the index I exceeds 200 and the comment "200 CITIES WERE PROCESSED" is written on TAPE3 and the program jumps to 22.

At 22 the value of INDX, the number of departure cities, is stored in MDEP. Then, the first two records in the TAPE2 file are skipped as they contain the program control data for the TRSRT program. Another DO loop with index I running from 1 to 200 is entered to process the arrival data. The values of KS is then initialized to 1. KS is used as an index value to make the search for the matching departure city more efficient. Next the arrival city record, ICTY, is read along with the number of flight records for that city, NARR. If an end of file is detected, processing jumps to 32 which is the normal exit of the DO loop. At this point a second DO loop is entered which runs from K=KS to MDEP, the number of departure cities. This loop is used to find the corresponding departure city. Since the arrival and departure data are often in generally the same order, the use of the value KS to start the search makes the search much more efficient. The current value of the index K is stored in KKS. KKS is used to save the value of the index K for which JCTY(K) equals the present arrival city ICTY. KKS is also used for resetting KS for the next search. A test is then made comparing the arrival city code ICTY with the stored departure city codes in the JCTY array. If the city is found, processing jumps to 27. Otherwise, the character comparisons continue until the DO parameter K is exhausted. If this occurs, another DO loop from K=1, KS is entered to search the remaining departure city codes for the arrival city code. Again, if the correspondence is found (ICTY=JCTY(K)), then processing jumps to 27. If no corresponding departure city in JCTY is found, the arrival city is added to the JCTY array. The value of INDX, the number of city records, is tested to see if there is sufficient space available in the JCTY array. If not, processing jumps to 25 and a comment is written on TAPE3 that the city record contained in ICTY was deleted from the processing. If space is available

in the JCTY array, the city counter, INDX, is incremented by 1 and JCTY(INDX) and NA(INDX) are assigned the values ICTY and NARR respectively. The value in INDX is assigned to KKS which contains the index of the JCTY array in which JCTY(KKS) and ICTY correspond. The search start index is set to 1 indicating that the next search for a corresponding arrival city, ICTY, and departure city KCTY(K) should start at the beginning of the JCTY array since no optimum start point exists. Processing then jumps to 28.

When a correspondence is found between the current arrival city, ICTY, and the departure city, JCTY(KKS), processing goes to 27. At 27, the search start index KS is set to the next element in the JCTY array (KS=KKS+1) to optimize the search for the next city read into ICTY from the TAPE2 file. This search optimization procedure is used to reduce search time. It works quite well because the cities in the TAPE1 and TAPE2 files are generally arranged in alphabetical order. If city names are randomly stored in the input files the search routine will not reduce computer execution time. Next, the arrival traffic count value NA(KKS) is set to NARR, the number of arrival flight records following the arrival city record.

At 28 an inner DO loop is initiated. This loop is used to read and evaluate the arrival flight records. Each flight record is read and the flight operating day parameters, IDAY and ICHAR, are sent to the IKEEP function to check to see whether the flight operates on the selected day, IDOW. If an end of file is detected during the READ instruction, processing jumps to 31 where an error comment is written. If the flight does not operate on the selected day, a value of 0 is assigned to IKP by IKEEP and the number of arrivals NA(KSS) is reduced by 1. This procedure is repeated until all of the arrival flight records have been processed and the inner DO loop on J=1, NARR has been exhausted. Then the outer DO loop on I=1, 200 is incremented and the next city card is processed. The normal exit of this DO loop on I occurs when an end of file is detected on the city card record and processing jumps to 32.

At 32, all of the data in the JCTY, ND and NA arrays are written on the TAPE3 and TAPE4 files. A comment is then written on TAPE3 that all data have been processed. Program control then jumps to 4 which is the beginning of the program. If no more data are to be processed an end of file is detected on the first READ instruction from TAPE1 and processing jumps to 99 and execution is terminated on a STOP instruction.

A.8.5 Program Listing

A listing of the TRPUN program is shown in Figure A.65.

```
      PROGRAM TRPUN(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
*  PROGRAM TO PUNCH TRAFFIC ROSE DATA FROM OAG DATA
      DIMENSION JCTY(200),ND(200),NA(200),TITLE(8),IDAY(7)
      DATA IBL/1H /
*  INITIALIZE VECTORS
4     DO 5 I=1,200
      JCTY(I)=IBL
      ND(I)=0
5     NA(I)=0
      IR=1
      IR2=2
      IW=3
      IPU=4
      INDX=0
      READ(IR,100) IDOW,TITLE
      IF(EOF(IR).NE.0.) GO TO 99
100   FORMAT(I1,8A4)
      READ(IR,110)
110   FORMAT(8A4)
      WRITE(IW,101) IDOW,TITLE
101   FORMAT(T5,32HTRAFFIC ROSE DATA PUNCH PROGRAM ,
     120HFOR DAY OF THE WEEK ,I1,1X,8A4//)
      DO 20 I=1,200
      READ(IR,102) ICTY,NDEP
      IF(EOF(IR).NE.0.) GO TO 22
102   FORMAT(T28,A3,T34,I3)
      INDX=INDX+1
      JCTY(I)=ICTY
      ND(I)=NDEP
      DO 20 J=1,NDEP
      READ(IR,103) ICHAR,IDAY
103   FORMAT(A1,7I1)
      IF(EOF(IR).NE.0.) GO TO 21
      IKP=IKEEP(ICHAR,IDAY,IDOW)
      IF(IKP.EQ.0) GO TO 19
      GO TO 20
19    ND(I)=ND(I)-1
20    CONTINUE
      WRITE(IW,200)
200   FORMAT(//T5,25H200 CITIES WERE PROCESSED)
      GO TO 22
21    WRITE(IW,201)
201   FORMAT(//T5,19HFLIGHT CARD MISSING)
*  READ ARRIVAL DATA SET
22    MDEP=INDX
      READ(IR2,110)
      READ(IR2,110)
      DO 30 I=1,200
      KS=1
      READ(IR2,102) ICTY,NARR
      IF(EOF(IR2).NE.0.) GO TO 32
      DO 23 K=KS,MDEP
      KKS=K
      IF(ICTY.EQ.JCTY(K)) GO TO 27
23    CONTINUE
      DO 24 K=1,KS
      KKS=K
      IF(ICTY.EQ.JCTY(K)) GO TO 27
24    CONTINUE
      IF(INDX.GE.200) GO TO 25
```

Figure A.65 TRPUN Program Listing (Page 1 of 2)

```
      INDX=INDX+1
      JCTY(INDX)=ICTY
      NA(INDX)=NARR
      KKS=INDX
      KS=1
      GO TO 28
25    WRITE(IW,202) ICTY
202   FORMAT(//T5,8HARRIVAL ,A4,32HDELETED, 200 CITY LIMIT EXCEEDED)
      GO TO 30
27    KS=KKS+1
      NA(KKS)=NARR
28    DO 29 J=1,NARR
      READ(IR2,103) ICHAR,IDAY
      IF(EOF(IR2).NE.0.) GO TO 31
      IKP=IKEEP(ICHAR,IDAY,IDOW)
      IF(IKP.EQ.1) GO TO 29
      NA(KKS)=NA(KKS)-1
29    CONTINUE
30    CONTINUE
31    WRITE(IW,210)
210   FORMAT(T5,27HARRIVAL FLIGHT CARD LISTING)
32    WRITE(IW,203) (JCTY(I),ND(I),NA(I),I=1,INDX)
203   FORMAT(T5,A3,I10,2I5)
      WRITE(IPU,204) (JCTY(I),ND(I),NA(I),I=1,INDX)
204   FORMAT(A3,I6,2I5)
      WRITE(IW,205)
205   FORMAT(//T5,27HALL DATA HAS BEEN PROCESSED)
      GO TO 4
99    STOP
      END
```

Figure A.65 TRPUN Program Listing (Page 2 of 2)